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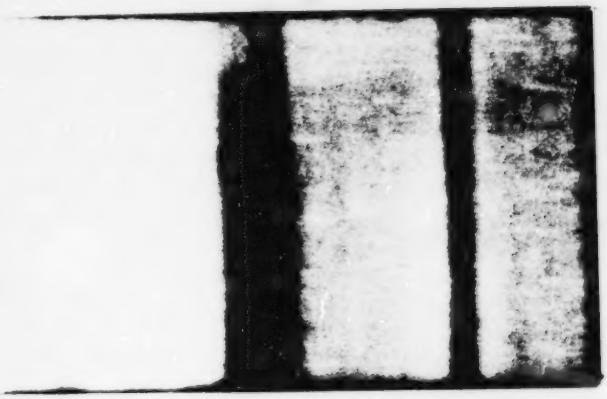

Waterloo Centre for Process Development

RHEOLOGY AND RHEOLOGICAL TESTING OF WESTERN CANADIAN BITUMINOUS COALS

-- FINAL REPORT --

This work was performed under a contract with
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I. SUMMARY

Rheology of three Western Canadian bituminous coals (low to high volatile) and two Appalachian bituminous coals (medium and high volatile) were determined from FSI measurements and dilatometry using a Ruhr instrument operated under German DIN standard test conditions as well as under non standard conditions. Coals were characterized by proximate and ultimate analysis. Petrography was also used to obtain maceral distribution and mean reflectance of the samples. Microlithotype analysis was undertaken as well. To provide a suite of ash and vitrinite content, coals were subjected to crushing and a specific gravity separation.

It was observed that the cretaceous coals of Western Canada could be made to approach the rheology of average coking coals by raising the top size of sample used in the dilatometer and increasing the rate of heating. Even when these steps were taken, dilatations measured were almost a decade lower than those seen for Appalachian coals of the same rank. It was found that the vitrinite content must be greater than about 55% for the Western Canadian coals if dilatation is to be measured. The explanation of the rheological differences may be associated with much higher ratios of semi fusinite to micrinite in the cretaceous Western Canadian coals than in the carboniferous Appalachian coals. Differences in particle size distributions in the samples may also contribute to the rheological differences.

II. INTRODUCTION

The properties of the plastic phase in the coal-to-coke transformation critically effect the resultant coke structure and strength. Since the real plastic properties, as exist in a coke oven, cannot be measured directly, standard bench scale tests are used to approximate them. Thus, we generate apparent plastic or rheological properties. It has always been assumed that the differences between real and apparent rheological properties are systematic and that a direct correlation exists between the two.

The strength of coke is known to depend upon the petrographic composition of the coal, its rank, the particle distribution of the charge, and the coking conditions. Thus, we assume that two coals of similar petrographic composition and rank, coked identically, and which produce indistinguishable cokes, would have passed through very similar real plastic phases.

Western Canadian coals, by many interpretations of apparent rheological properties, should not form coherent coke. The fact that they do contradicts or at least leaves incomplete, our understanding of the relationship of petrography, rheology, and resultant coke quality.

The successful application of applied coal petrography to Western Canadian coals directs our attention to coal rheology. Do the apparent rheological properties of Western Canadian coals relate to the real properties in the same manner as they do for other coals?

This is the general question attacked in this contract. The first question to be resolved is how satisfactory are the procedures for measuring the apparent rheological properties? How significant are the test conditions to the results of the measurement? Does the influence of test conditions depend on the coal and its petrographic properties? Ultimately, our goal is to develop rheological tests for Western Canadian coals which predict coking performance as well as the present tests predict performance for the carboniferous coals.

There are three popular methods for determining a coal's apparent plastic properties - free swelling index, plastometry and dilatometry.

- The free swelling index (FSI) is a quick if somewhat crude method. Basically, higher FSI's mean better plastic properties.

- The most commonly used plastometer - the Gieseler - yields a more detailed appraisal of rheology. It identifies softening and solidification temperatures, the interim plastic range, and measures a

plasticity analagous to viscosity - expressed in dial divisions per minute (ddpm) of a coal as it becomes plastic.

- The dilatometer most widely accepted in Canada is the one originally developed in West Germany - the Ruhr Dilatometer. It provides a plastic temperature range and measures the coal's propensity to contract and to swell - an indication of the plastic phase properties of the coal.

In this work, measurements of FSI and dilatometry (Ruhr Method) will be considered. Plastometry is the subject of an extension contract which we are now undertaking.

Makowsky and Wolff (1966) and Juranek (1982), among others*, have described how the apparent rheological properties of coals can be manipulated by test conditions and procedures. Following this lead, we have in a separate study (Ramachandran, 1983) verified the positive effects of increased particle size and of faster heating rates on the measured rheological properties of Western Canadian coals. Work under this contract builds on Ramachandran's investigations, expanding the range of coals tested, undertaking ash removal and some specific gravity fractionating of the coals, and extensively documenting the chemical and petrological properties of the coals in relation to their apparent rheology. Our intent was to artifically generate a diverse sample suite through stage crushing and specific gravity separation, to determine the rheology, and then to relate our observations to petrology and other coal properties.

In what follows, we attempt to present a rationalization of the data, as opposed to a statistical analysis, admitting the exploratory nature of the work, the limited number of coals considered, and, then too the difficulties in assimilating the sheer amount of diverse data.

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* Rather than inflate this report by pages of a literature survey, we refer to a comprehensive and detailed review prepared by Ramachandran of our research group as part of his MASc. Thesis (Ramachandran, 1983). This thesis is part of the public record.

III. WORK STATEMENT

The research undertaken under this contract is well stated by the Work Statement which was part of the contract document.. Deviations agreed to by the Scientific Officer are mentioned in the following sections. The work was broken down into specific tasks.

Task 1 Three, high-inert western Canadian coals having good coking or blending properties will be solicited in consultation with CANMET scientists for this study. The coals will be high, medium and low-volatile in ASTM rank. Petrographic (reflectance, maceral and lithotype) analyses; proximate, ultimate, and ash analyses will be made on each coal.

Task 2 Three Appalachian coals will be solicited to compare with the Canadian coals. These will be selected so that each will have an R_o from petrographic analyses within 0.05% of one of the Canadian coals. Petrographic, proximate and ultimate analyses will be made on representative samples of each coal. Representative samples will be obtained by splitting, riffling, or other ASTM approved method.

Task 3 A suitably sized representative fraction of each of the six coals will be pulverized to 3 particle size consists, each of which is similar for all six coals. A decision on the consists used will be made in consultation with CANMET. A complete screen analyses (6 screens), or some alternative particle size distribution technique, will be made for each of the 18 coal samples.

Task 4 (A) Ruhr dilatation measurements according to the DIN standard will be made in duplicate on each of the above 18 samples.

(B) Ruhr dilatation measurements will also be made in duplicate at a second heating rate with one comparable size consist for each of the 6 coals.

(C) Ruhr dilatation measurements will be made with 2 heating rates and one size consist of each coal at two compaction levels - 12 additional tests in duplicate.

Results from each single dilatation determination will be reported so that reproducibility of duplicate testing can be assessed.

Task 5 FSI measurements will be made in triplicate on each of the 18 coal samples generated in Task 3.

Task 6 Suitably sized representative fraction of two of the western Canadian coals and two of the Appalachian coals (selected in Tasks 1 and 2) will be washed at 3 specific gravities to split these coals into coals of 3 ash levels. Petrographic, proximate, and ultimate analyses will be made on each sample.

Task 7 A suitably sized representative fraction of each of the above 12 samples will be stage crushed to obtain 3 different fractions (36 samples).

Task 8 Petrographic and proximate analyses will be made on representative samples of each of the 36 materials generated. An additional 9 ultimate analyses will be done on one of the western Canadian coals (3 ash levels x 3 fractions from stage crushing).

Task 9 The 36 samples will be pulverized to two particle size consists (each of which is similar for the 36 samples). A complete screen analysis will be reported for all 72 samples.

Task 10 Ruhr dilatation measurements will be made in duplicate on a representative fraction of each of the 72 samples generated in Tasks 6, 7 and 9.

Task 11 FSI measurements will be made in triplicate on a representative fraction of each of the 72 samples generated.

Task 12 1.5g portion of all FSI and dilatation residues from Tasks 4, 5, 10 and 11 will be suitably labelled and sent to CANMET for analyses (possibly textural analyses). The remainder of the samples will be stored for further analysis. Samples of the original coal used for each test will also be kept.

Task 13 Final Report: The final report will describe all sampling and experimental procedures used throughout the work. All experimental results will be appended as tables in the report. Chapters will discuss, summarize and compare the effects of size consist, heating rates, density and petrographic characteristics on the thermal and rheological properties of western Canadian and Appalachian coals. Additional chapters will discuss the effects of ash, particle size consist and maceral and lithotype on the thermal and rheological properties of each coal.

IV. EXPERIMENTAL PROGRAM

Five raw coal samples were obtained for this study from mine operators or from CANMET. These samples will be identified as follows:

Coal C1: A Western Canadian coal of the Luscar formation, low-volatile bituminous by ASTM classification but with a vitrinite reflectance more typical of medium-volatile coal. It is very inert rich.

Coal C2: A Western Canadian coal of the Kootenay formation, ASTM ranked as medium-volatile bituminous, agreeing with its mean reflectance. It is inert rich.

Coal C3: A Western Canadian coal of the Kootenay formation, both by ASTM classification and by reflectance a high-volatile "A" bituminous coal.

Coal A1: A high-volatile "A" bituminous coal from Kentucky of strong coking potential.

Coal A2: A medium-volatile bituminous coal from Virginia, again of very strong coking potential.

Proximate analysis of these coals are to be found in Tables C1-2, C2-2, C3-2, A1-2 of Appendix A.

Because of the petrographic similarities of the C1 and C2 samples, clean samples of these coals were obtained and a nearly full suite of tests were performed on the cleaned samples. Proximately analyses for the clean coal samples are located in Tables C1-2 and C2-2. Reflectances for these coals are given in Tables C1-3B and C2-3B. The measurements confirmed that sample C1 was anomalous so that we would not assume that we had a Western Canadian low volatile bituminous coal that could be meaningfully compared with an Appalachian low volatile bituminous coal. As a consequence our Work Statement was modified with the permission of the Scientific Officer to drop out the low volatile Appalachian coal. This occurred late in the contract when the low volatile sample had not yet been received.

Raw coal samples were crushed to pass a 4 mesh screen. Portions of each sample were screened to yield 8x0 and 20x0 cuts in addition to the original 4x0 material. Each cut was then further separated by sink-float procedures at specific gravities of 1.4, 1.5 and 1.6 as set forth in the Work Statement (see Section III).

The specific gravity separated were carried out in "Certigrav" fluids. These are mixtures of volatile dichloro and dibromoethane. Separations were found to be clean; only the 20x0 fractions were centrifuged to assist in separation. The float cuts, removed by decanting, were washed in methanol and vacuum dried for a short time to remove traces of the Certigrav fluids. Sample oxidation was minimized by storage in evacuated desiccators. In most cases, analyses were performed soon after the samples were prepared (within weeks) . Tests to detect oxidation were not performed. Work up of the samples is set out in Figure 1.

All samples employed were subjected to sieve analysis down to -100 mesh. Proximate analyses were performed on all samples, except the A2

coal, raw coal and the C3, A1, A2 coals. Ultimate analyses were run only on the B suite of materials, that is, samples prepared by crushing/ sieving/gravity separation.

Further characterization of the samples by petrography was undertaken. Maceral counts were performed and vitrinite reflectance was determined on all samples except the clean A1 and A2 coals. Only the B suite of samples were subjected to microlithotype analysis.

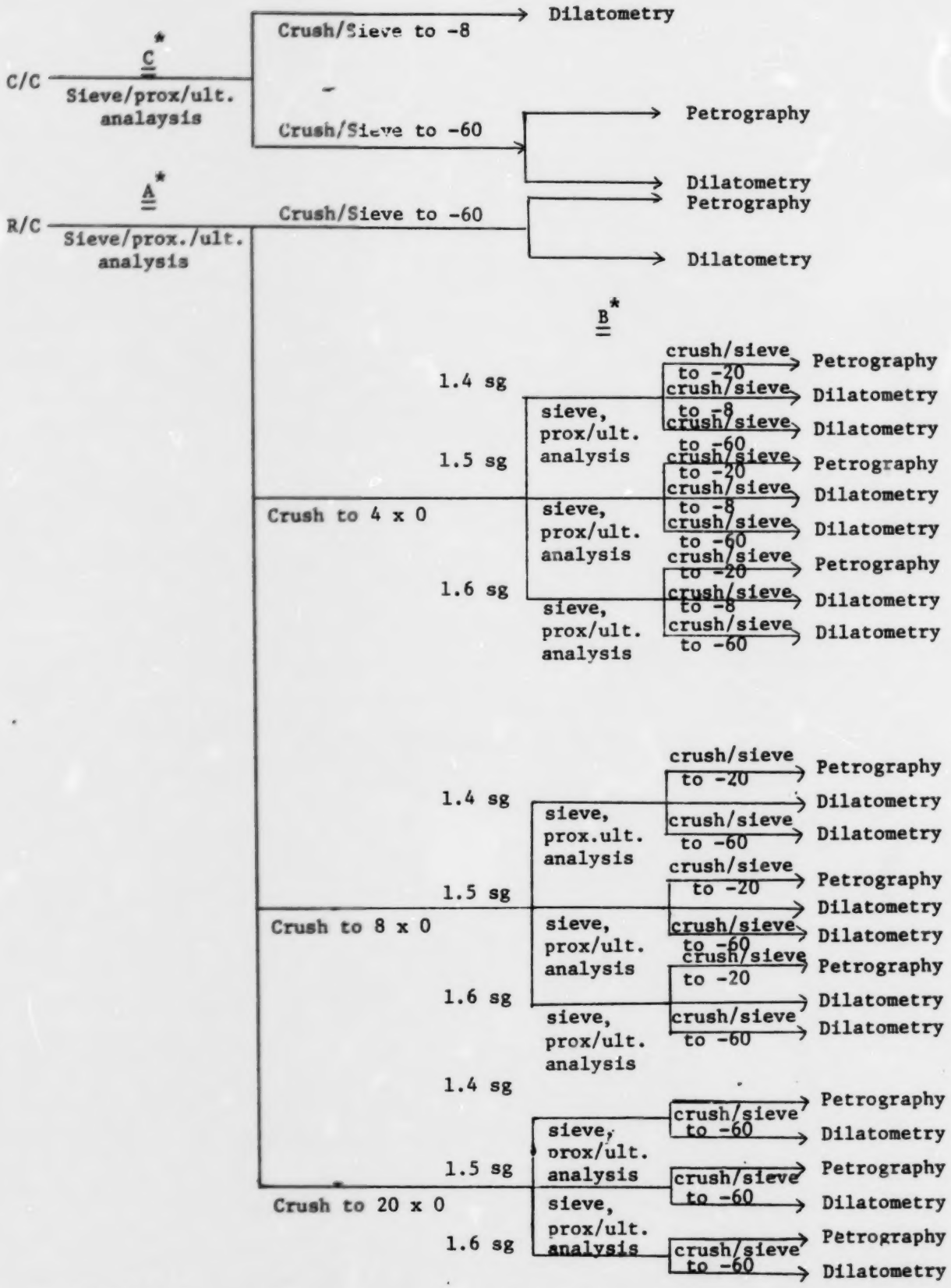
The characterization program followed in this study is summarized in Table 1.

With the exception of ultimate analysis and the dilatometer measurements, procedures used by Stelco were used in both the sample characterization and rheological tests. These procedures were identical to or closely follow ASTM and/or ISO tests. Table 2 describes the tests used and givestheir sources in books or manuals.

Ultimate analyses were performed on a Perkins-Elmer Elemental Analyzer. Although this instrument is not covered as yet by an ASTM standard, measurements on known samples shows its results to be accurate and highly reproducible. Because of the delicacy of the instrument, measurements were made for us by Prof. H.D. Sharma of the Waterloo Chemistry Department. Initially, the instrument was not capable of providing accurate sulfur measurements. For much of the time frame of this contract, total sulfur was performed on a LECO Total Sulfur Analyzer. The manufacturer's procedure was followed.

Rheological properties of the samples (see Figure 1) were obtained by measuring the Free Swelling Index (FSI) and using a dilatometer built to the Ruhr standard design. Table 1 shows the samples used for these tests.

FSI measurements followed ASTM procedures. The standard is quoted in Table 2.



* See Table 1

Figure 1. Schematic of Sample Preparation

Table 1: Analytical Schedule

Test Class	A					B							C		
Type of Coal	R/C					C/C from Float-Sink							C/C		
Coal Source	C_1	C_2	C_3	A_1	A_2	C_1	C_2	C_3	A_1	A_2	C_1	C_2	C_3	A_1	A_2
Sieve analyses	x	x		x	x	x	x	x		x	x	x	x		
Proximate analyses	x	x	x	x		x	x	x	x	x	x	x			
Ultimate analyses						x	x	x	x	x					
F.S.I.	x	x	x	x	x	x	x	x	x	x	x	x			
Petrographic analyses															
Mean R_o %	x	x	x			x	x	x	x	x	x	x			
Maceral counts	x	x	x			x	x	x	x	x	x	x			
Microlithotype analyses						x	x	x	x	x					
Dilatometry															
Standard Condition DIN	x		x			x	x	x	x	x	x	x			
Non-standard Condition			x			x	x	x	x	x	x	x	x		

R/C - Raw Coal
C/C - Clean Coal

Table 2:
Description of Analytical Procedures

1. PROXIMATE ANALYSIS
Followed "Methods Manual for Coals and Coke Analysis", Research and Development Department, Stelco Limited, Hamilton. This conforms to procedures in Part 26 on pages 370-72 L977 Annual Book of ASTM Standard.

2. ULTIMATE ANALYSIS
Not according to ASTM standards. Measurements performed using a Perkins-Elmer Elemental Analyzer, Model 240C.

3. TOTAL SULFUR ANALYSIS
Measurements made with a LECO Automatic Sulfur Titrator Model 532. There appears to be no ASTM standard for the use of the LECO instrument Manufacturers instructions were followed.

4. SIEVE (PARTICLE SIZE) ANALYSIS
Carried out according to standards D-311-30-1969 "Sieve Analysis of Crushed Bituminous Coal", page 30 of the 1969 Annual Book of ASTM Standards.

5. PETROGRAPHIC CHARACTERIZATION
A Carl Zeiss Universal Microscopic equipped with petrography accessories was employed. Maceral counts and reflectance measurements were performed following standard D-2798-77, 1977 Annual Book of ASTM Standards.

6. MICROLITHOTYPE ANALYSIS
Based on Stopes Classification using 100 counts for the same pellets used in petrographic analysis; a non standard procedure was employed as given on pages 257-8 of "Stach's Textbook of Coal Petrology" Borntrager, Berlin, 1975.

7. PREPARATION AND POLISHING OF PETROGRAPHIC SAMPLES
Followed the procedure in Cole, L. Berry, W.S. "Preparation and Polishing of Coal Pellets for Petrographic Analysis" National Research Assn. for Bituminous Coal (1965) with modifications in grinding and polishing times to improve final, polished pellets.

8. DILATOMETRY
An ASTM standard does not exist for the Ruhr Dilatometer. Procedure taken from a translation into English of West German Standard DIN 51739 by J.G. Jorgenson (1971) with modifications employed by STELCO as given in Methods Manual for Coal and Coke Analysis.

9. FREE SWELLING INDEX
Followed the "Methods Manual for Coal and Coke Analysis" Research and Development Division, Stelco Limited. The procedure is essentially the one given in Part 26, pages 244-50, 1977 Annual Book of ASTM Standards.

10. SAMPLING PROCEDURE
Followed the ASTM Standard D-2013.

11. SPECIFIC GRAVITY SEPARATIONS
Float-sink procedure followed "Methods of Analyzing and Testing Coal and Coke", US Bureau of Mines, Bulletin #638 (1967) pp. 30-35.

A highly automated research model dilatometer built to DIN 51739 by Standard Instrumentation of Charleston, West Virginia was used. Figure 2 sketches the Ruhr design and also the pencil forming accessories. The dilatometer consists of a cylindrical aluminum-bronze furnace block heated electrically by a resistance winding. As shown in the figure, two of the three equally spaced holes hold the dilatometer tubes which in turn hold the coal pencils on which are placed the dilatometer pistons. The third hole contains the thermocouple used for temperature sensing and control. The recording apparatus, shown in the figure, has been replaced by electronic sensors. A digital record of expansion and contraction versus time and temperature was produced by the instrument. The pencil mould, shown also in Figure 2, has an internal taper of 1:50 and is used to make pencils of 60mm length. The ram was used to initially compact the coal powder within the mould. Further compaction was done using the spindle press. The pencil was ejected from the mould using the press with the mould plug and base removed.

The design is not fully standardized as may be seen in Appendix B which compares different specifications.

Our research unit was equipped with a temperature programmer/controller that allowed a linear temperature rise between 100°C and about 600°C at any rate up to about 5°C/min. A rate up to 6°C/min could be used but the rise was no longer linear (the advertised rate of 10°C/min for the instrument could not be achieved).

In addition to the DIN 51739 heating rate of 3°C/min, a 4.5°C/min rate was selected as a non-standard condition (based on instrument limitation, reproducibility, cycle time, and instrument maintenance. This choice represents, of course, a 50% increase in rate.

The DIN Standards call for 0.2mm or minus 60 mesh coal to be tested. Based on Ramachandran's work, and considering the fact that the Western Canadian coal samples acquired exhibited little or no dilatation under standard conditions, we chose an extreme non-standard size fraction of minus 8 mesh. This, according to Ramachandran, produced much higher

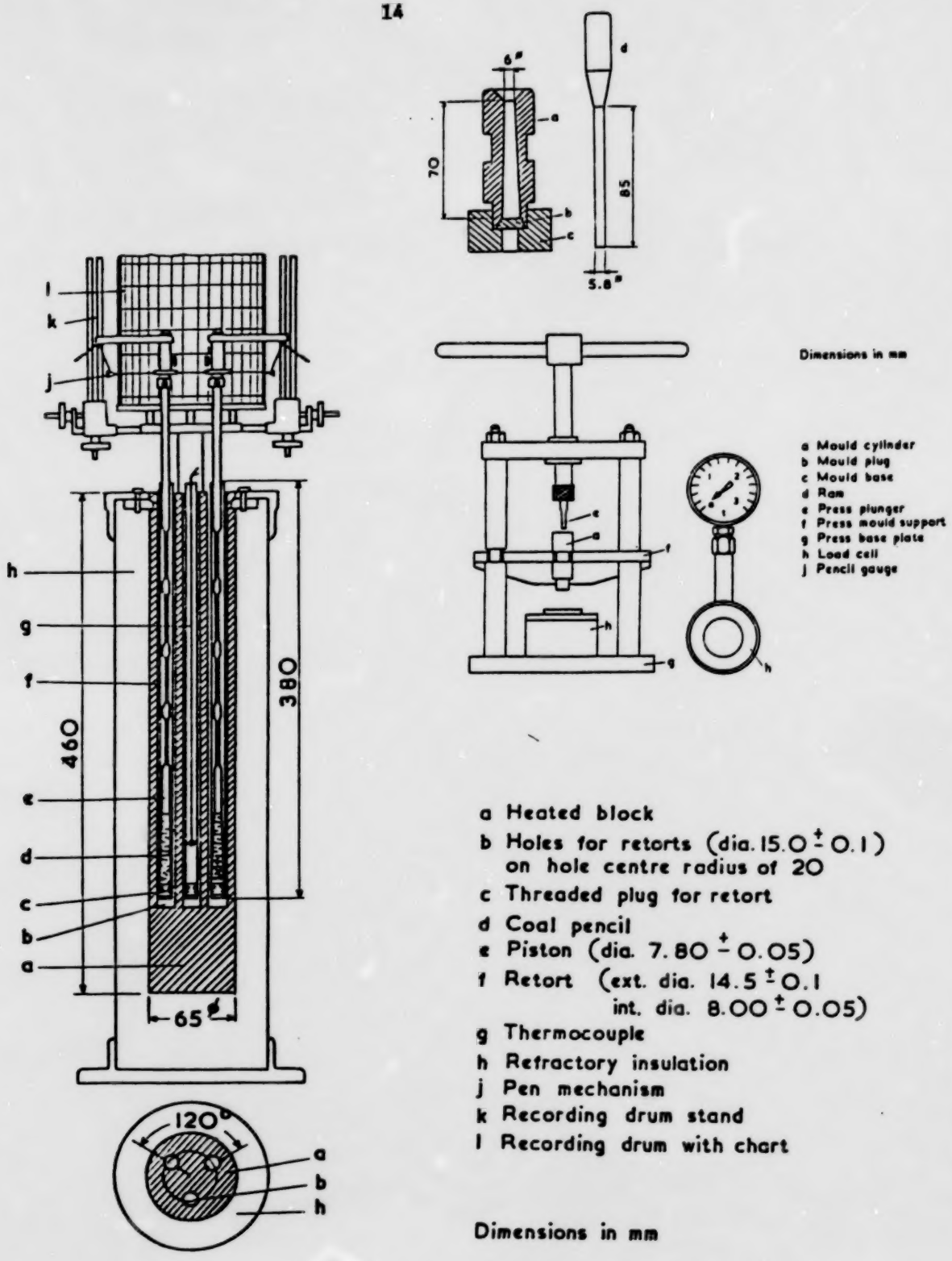


Figure 2 - Schematic Diagrams of the Ruhr Dilatometer and the Pencil Moulding Accessories

dilatation. Of course, this choice eliminated non-standard dilatometry on the 20x0 cut but we justified this in our minds by the data to be generated on the other samples.

There are five data generated in a dilatometer test:

Ti - initial softening temperature (°C)

Tii - temperature of maximum contraction (°C)

Tiii - temperature of maximum dilatation; also equivalent to solidification temperature (°C)

c - contraction (%)

d - dilatation (%)

The contraction and dilatation are expressed as a percent of the initial pencil length; thus negative values of dilatation can result. A strong measure of the coal's plastic character is the sum c + d. We refer to this further on as total dilatation.

Analysis of the ash composition was undertaken by flame photometry. The results were wildly inaccurate for all samples (e.g. silica wt. percents of 1 to 3%) and have not been reported. The photometer used has a history of erratic behaviour, but we attribute the erroneous analysis to a systematic error in the photometric standards used. The absence of the ash analysis represents a deviation from the Work Statement.

V. EXPERIMENTAL RESULTS

Data collected for the measurements given in Table 1 are contained in Appendix A.

Rheological properties of coking coal are traditionally associated with the vitrinite content. In Figure 3 we examine the variation of the vitrinoid fraction with the level of cleaning, expressed in terms of ash content encountered in the study. Figure 3 demonstrates that the Western Canadian coals can be substantially enriched in vitrinoid by washing. Increasing the grinding, releases ash and raises the vitrinite content. For the Appalachian coals, vitrinoid enrichment with cleaning is substantially less.

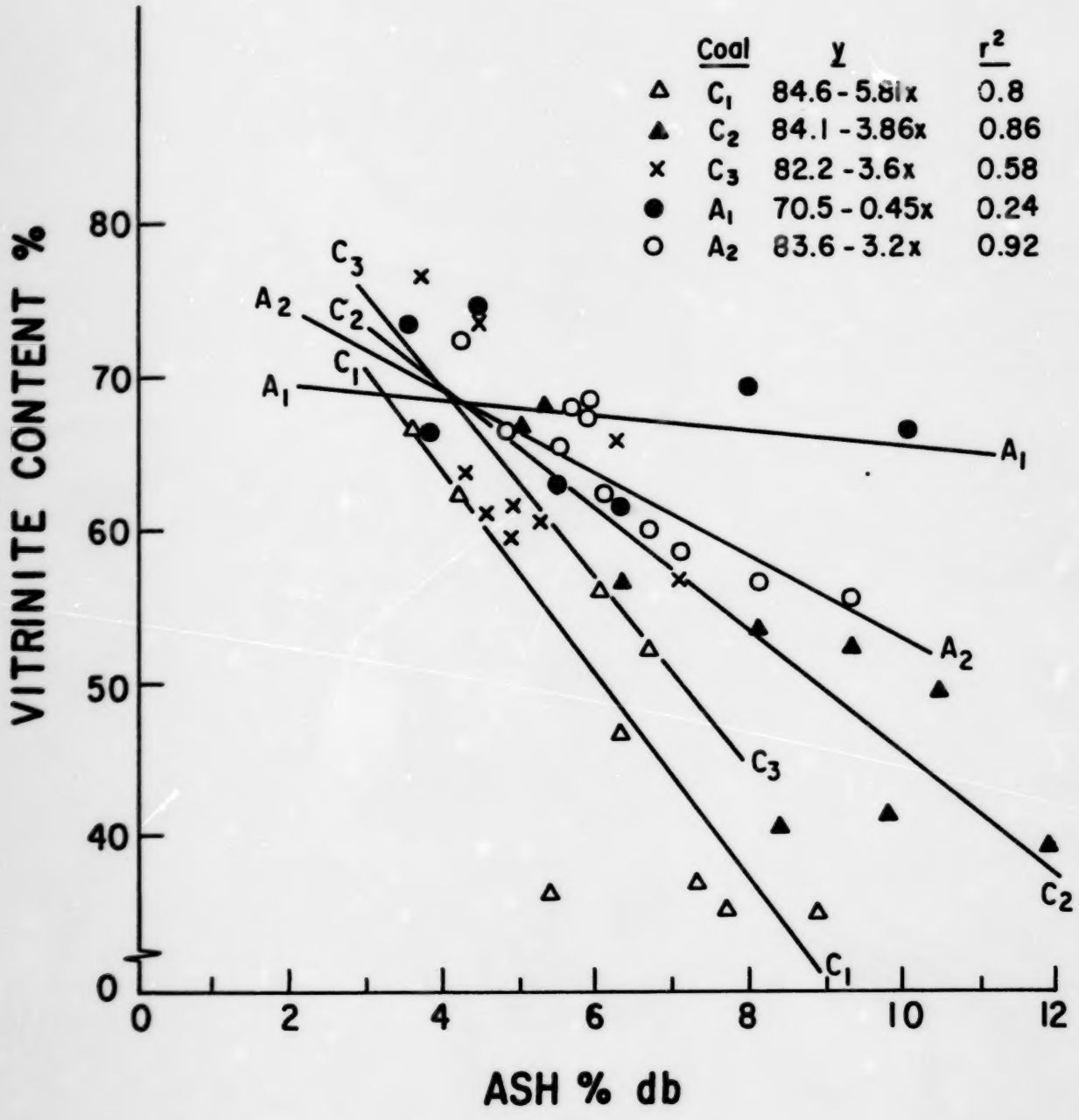


Figure 3. Vitrinite vs. Ash Content in the Five Coals Studied

Figures 4 and 5 cross plots content of the other macerals against the area (or point) percent vitrinoid. Semi-fusinites are considered in the first of these figures. Substantial differences can be seen. Semi-fusinite is two to three times higher in Western Canadian cretaceous coals than is the Appalachian carboniferous samples. Although separate linear regression lines have been fitted to the data for the different coals, the Western Canadian coals yield, essentially, a single curve showing a trade off in these coals between semi-fusinite and vitrinite. On the other hand, semi-fusinite remains about constant in the Applachian coals despite a 20% variation in the vitrinite content. Closer examination of the data shows grinding has only a small effect on the semi-fusinite level for these coals.

The micrinite and fusinite contents are given in Figure 5. With micrinite, the relationship seen in Figure 4 is reversed. The Appalachian coals have about twice the micrinite seen in the Western Canadian samples. Although separate regression lines have been drawn for the A1 and A2 samples, the scatter and overlapping of the data points suggests this is unnecessary. On the other hand, the C1 and C2 coals show quite different behaviour despite the closeness of their vitrinoid reflectance.

Fusinite data are badly scattered, so the regression fits are of doubtful validity. Nonethless, except at high vitrinite content, the Appalachian coals show somewhat lower fusinite content than do the C1 to C3 samples.

Carbon-hydrogen weight ratios are plotted versus vitrinite content in Figure 6. These ratios correlate closely with the mean reflectance as may be seen in the figure. The figure shows that the C/H ratio, like the mean reflectance, depends primarily on the coal. Very little dependence on vitrinite content can be seen.

Mean reflectance measurements are given Tables C1-3B, C2-3B, C3-3B, A1-3B, A2-3B.

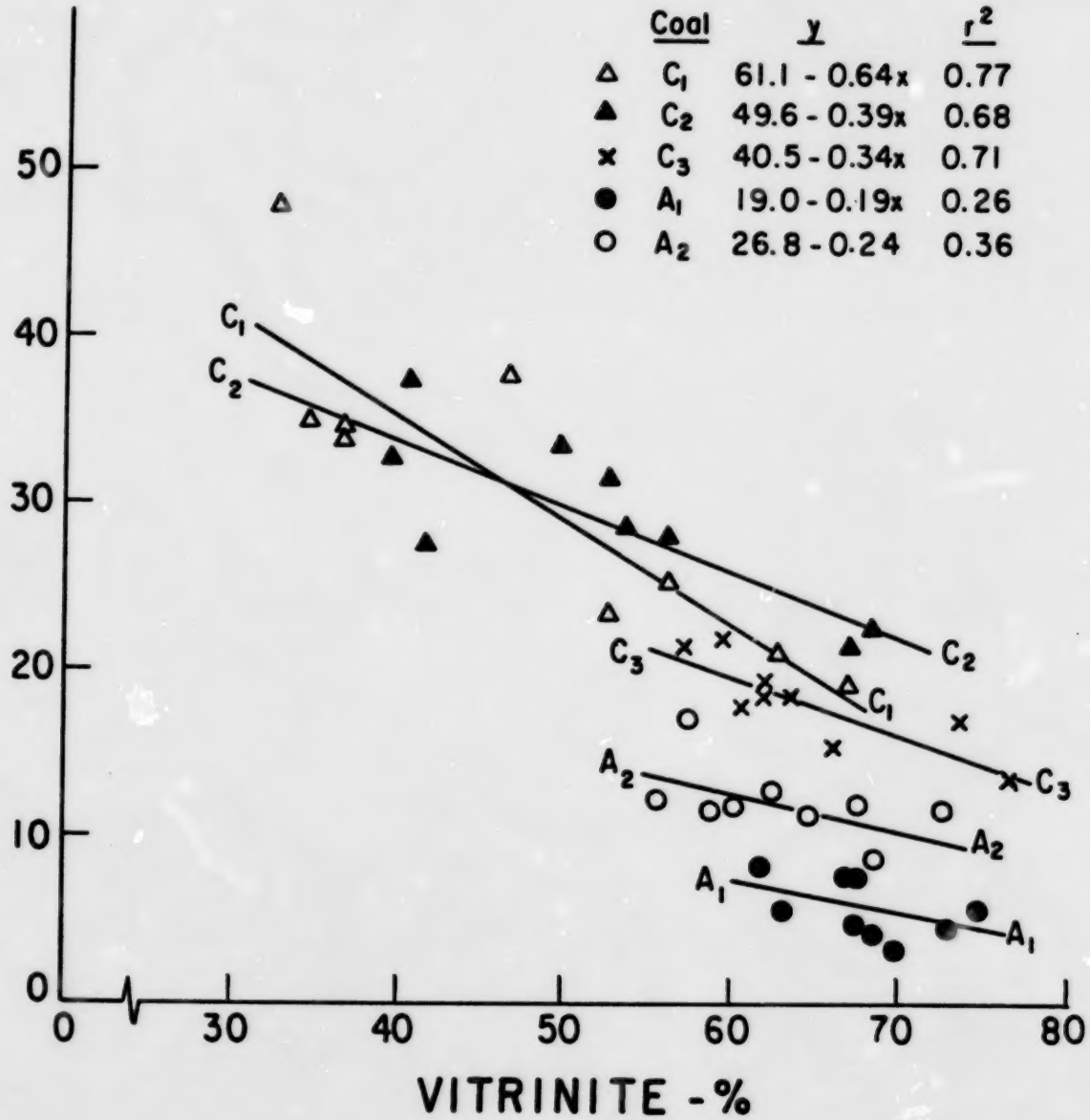
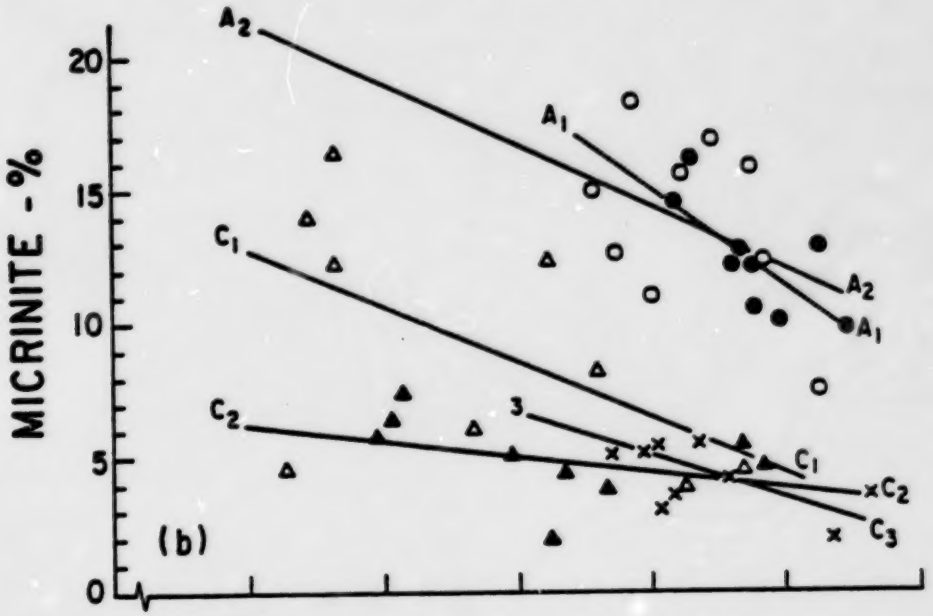


Figure 4. Semi Fusinite vs. Vitrinite Content in the Coals Studied

(a) Micrinite



(b) Fusinite

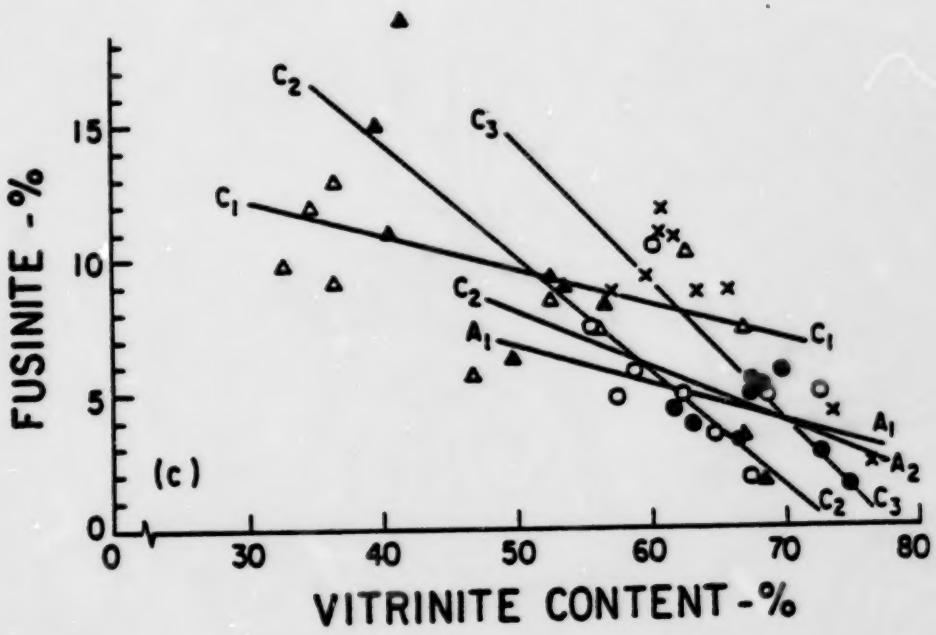


Figure 5. Other Macerals versus Vitrinite Content in Test Coals

	Coal	Fig. 3b y	Fig. 3b r^2	Fig. 3c y	Fig. 3c r^2
△	C_1	18.9 - 0.21x	0.32	13.7 - 0.09x	0.27
▲	C_2	8.4 - 0.07x	0.19	31.5 - 0.43x	0.78
×	C_3	11.3 - 0.11x	0.35	35.9 - 0.43x	0.78
●	A_1	37.0 - 0.36x	0.54	14.7 - 0.16x	0.21
○	A_2	30.4 - 0.26x	0.20	18.3 - 0.20x	0.22

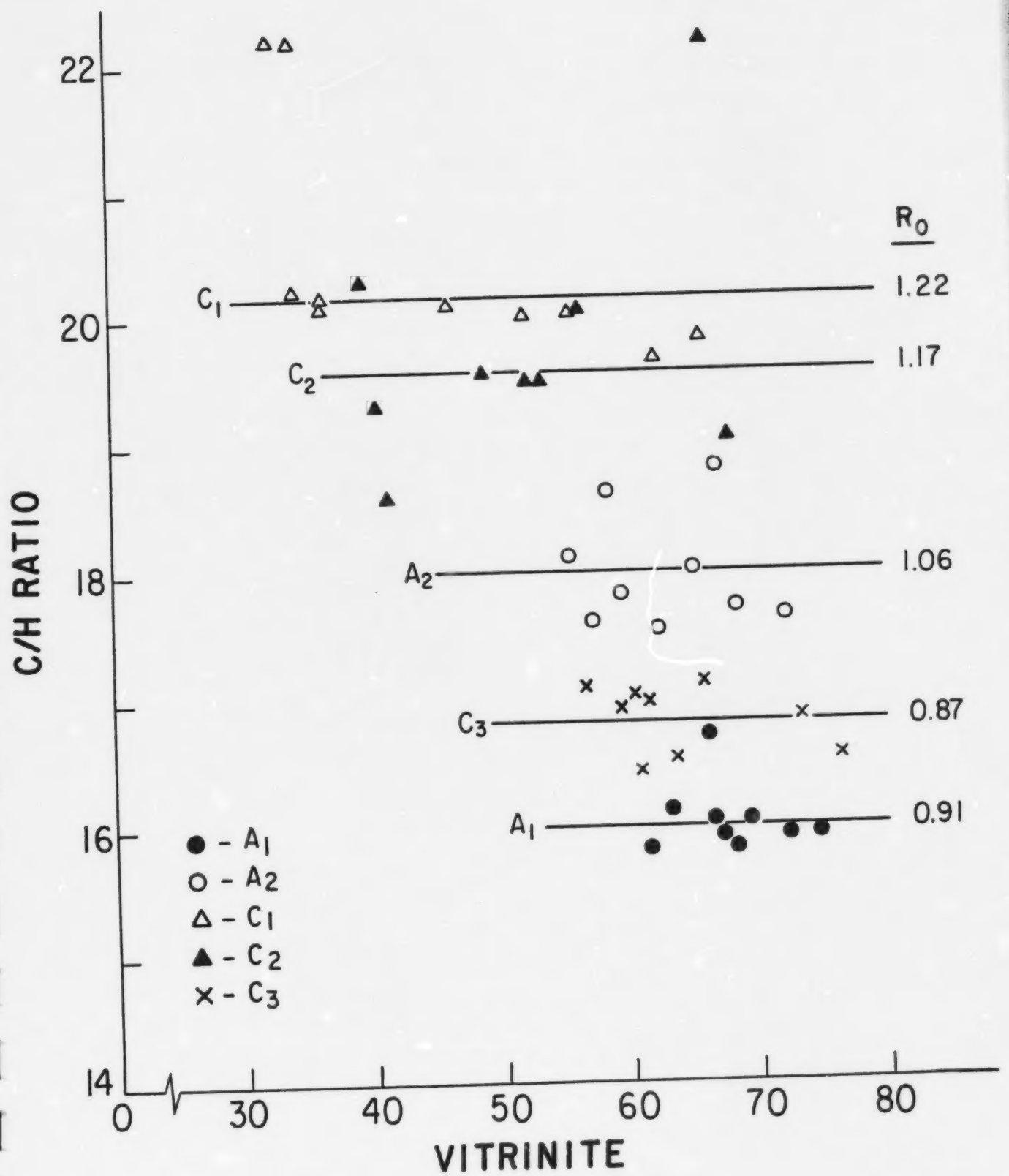


Figure 6. C/H Ratio vs. Vitrinite Content for Coals Studied (Mean Reflectance Drawn at the Mean C/H Ratio for each Coal.)

In Figure 7, the total dilatation of the pencil, that is contraction plus dilatation is plotted versus vitrinite content for the Western Canadian cretaceous coals under the standard Ruhr conditions. Figure 10 repeats the plot, but for the carboniferous Appalachian coals, while Figures 8, 9 and 11 consider total dilatation under non-standard conditions.

Standard Ruhr conditions depend somewhat on the user as may be seen in Appendix B. For this study as well as Ramachandran's work (1983), we consider 3°C/min, a -60 sample and a mold compaction force of 3000 lb_f to be standard. However, Ramachandran observed that compaction force had only a negligible influence on rheology so we have treated data collected at 4300 lb_f as standard conditions. Indeed, Appendix B shows wide variation in compaction force (and method) between the different recipes.

Under the standard Ruhr test conditions, the Western Canadian samples exhibited little or no total dilatation. For the anomalous low volatile coal (C1), some total dilatation appears when the vitrinite level exceeds about 55%. On the other hand, apart from a single sample, the medium volatile C2 coal requires about 65% vitrinite for total dilatation to appear, whereas the high volatile sample may need more than 70% vitrinites.

The effect of using a coarser sample of the cretaceous coals is explained in Figure 8. There appears to be little influence of particle size on the C1 coal. The total dilatation does not change significantly and apparently a vitrinite content of 55% is still needed for $c + d > 0$. There is no evident change for the C2 coal as well, however, in both cases there are too few data points with significant dilatations to pass a definitive judgement. For the high volatile sample, however, particle size has an enormous effect. Above a $c + d$ of about 55%, $c + d$ increases by about an order or magnitude.

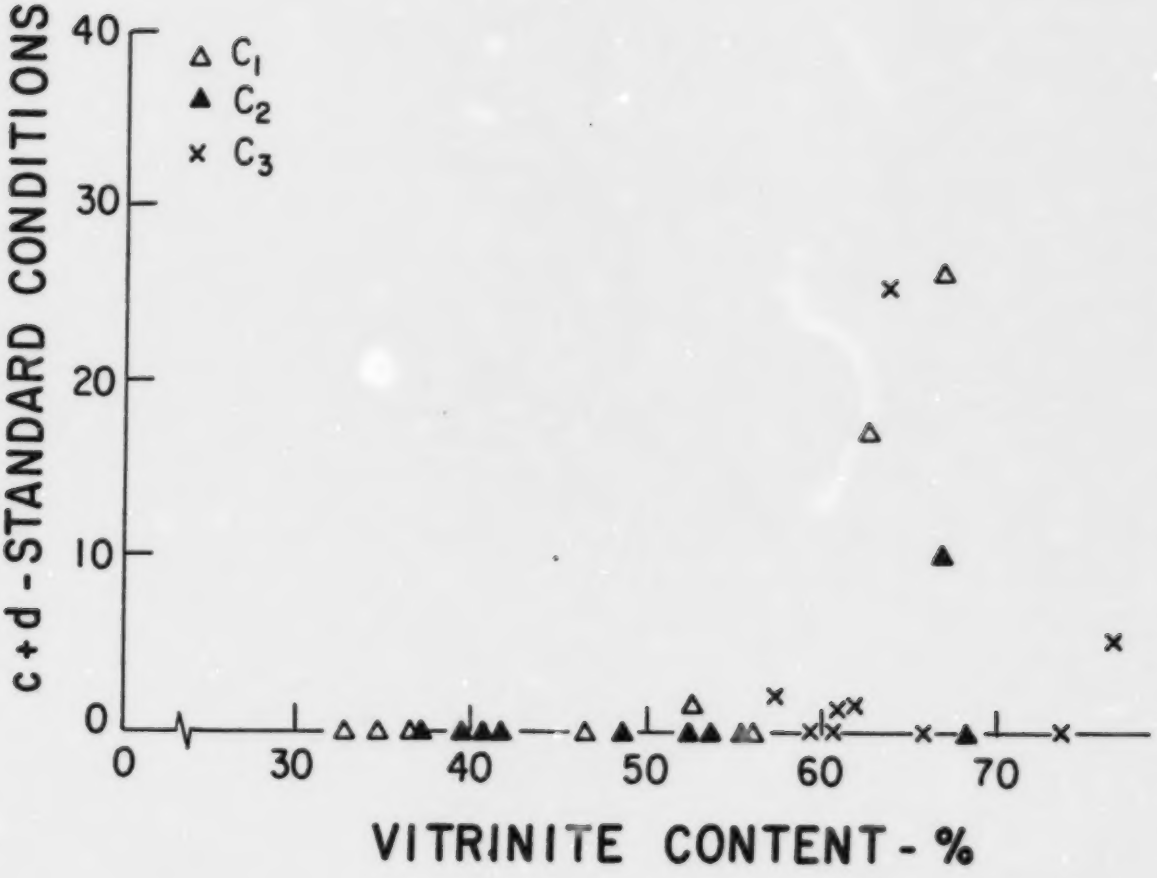


Figure 7. Contraction and Dilatation of Western Canadian Coals with the Ruhr Dilatometer at Standard Conditions (3°C/min, -60 , 4300 psi) Versus Vitrinite Content

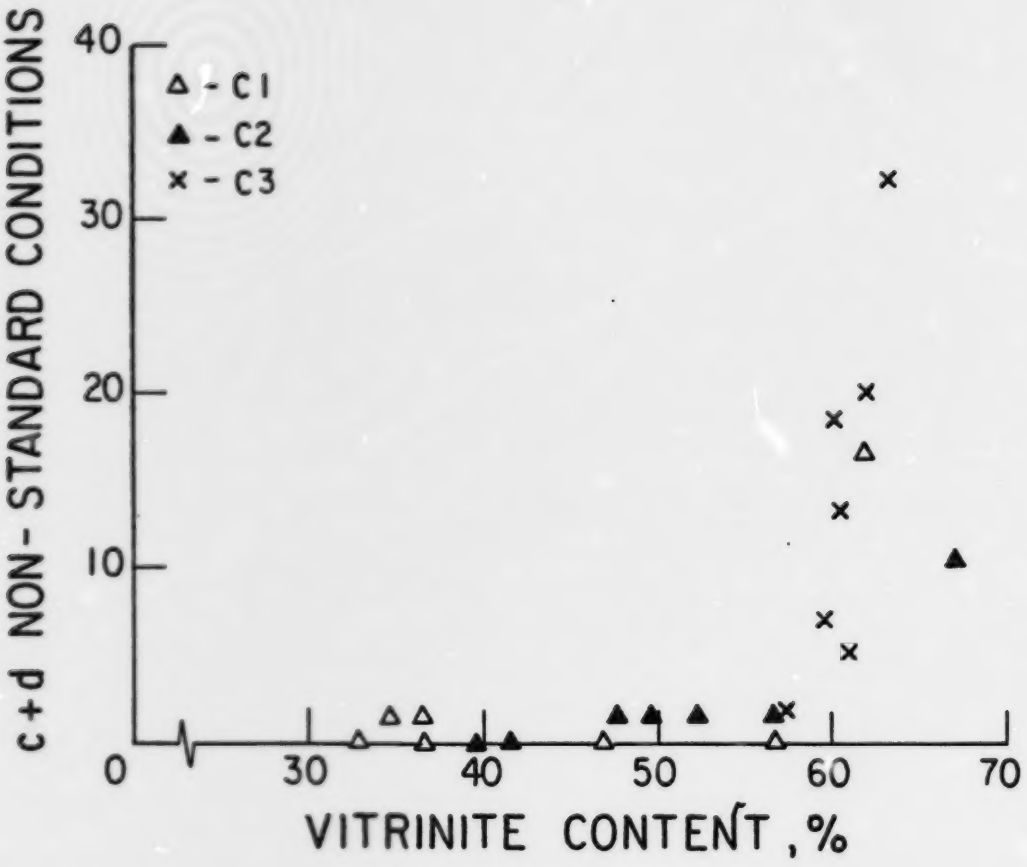


Figure 8 Contraction + Dilatation with the Ruhr Dilatometer for Western Canadian Coals at Non-Standard Conditions (3°C/min, [-8], 3000 psi) vs. Vitrinite Content

In Figure 9, the influence of a 50% rise in the heating rate can be seen to give a further increase in the total dilatation. Dilatation is now evident at 50 to 55% vitrinite for all the coals.

The Appalachian coals all show strong dilatation under the standard Ruhr test conditions. As expected the medium volatile sample exhibits a strong total dilatation vitrinite correlation. Although we show a regression line in Figure 10 for coal A1, there is effectively no relationship. It may be that for this rank of coal, c + d is insensitive to vitrinite content under DIN conditions. Note, however, the very high c + d values of both coals even at low vitrinite levels.

Employing non standard Ruhr conditions of 4.5°C/min, -8 samples and 4300 lb_f increases c + d by 20 to 40% for both Appalachian coals. Figure 11 shows the c + d vs. vitrinite plot. The c + d - vitrinite slope for the A2 coal is virtually unchanged by the non-standard test conditions whereas for the medium volatile sample, total dilatation now becomes a strong function of the vitrinite level.

Temperature measurements in dilatometer may be summarized as follows:

	Coal Suite				
	Western Canadian			Appalachian	
	C1	C2	C3	A1	A2
Initial Softening (T_i)	↓	↓	↑	-	-
Maximum Contraction (T_{ii})	↓	↓	↓	↓	↓
Maximum Dilatation (T_{iii})	?	?	↑	↑	-

In the above ↓ means the temperature drops in shifting to non-standard Ruhr conditions, ↑ indicates a rise, - indicates contradictory results and ? means that observations did not suffice to note a change. In general, larger changes in temperature resulted from the specific gravity used for separation and the extent of crushing. These changes seemed to reflect vitrinite content.

Ramachandran (1983) points out that roundoff in the digital output in the automated Ruhr instrument used leads to a 10 to 20°C uncertainty in T_i and 5 to 10°C uncertainty in T_{ii} and T_{iii}. Uncertainty is about the same as the shifts oberved for changing test conditions. Because of this, temperatures will not be used further in interpreting this study, except for their incorporation in the G factor.

Figure 12 shows the variation of the Free Swelling Index relative to vitrinite content for all five coal sample suites. Both the cretaceous and carboniferous samples seem to form a single data population but with considerable scatter. Reasonably high FSI values were determined on the C1 and C2 coals which showed no swelling properties in the dilatometer under any test conditions. However, even at the same vitrinite levels, the high volatile U.S. coal is 1 to 2 FSI numbers higher than the Western Canadian coal of similar rank. The difference may be even larger for medium volatile samples. Whereas the Western Canadian coals show FSI to depend on vitrinite content, this dependance has disappeared for the Appalachian coals, even though dilatometry relates well to vitrinites. Probably the FSI scales are too crude for the dependance to show up.

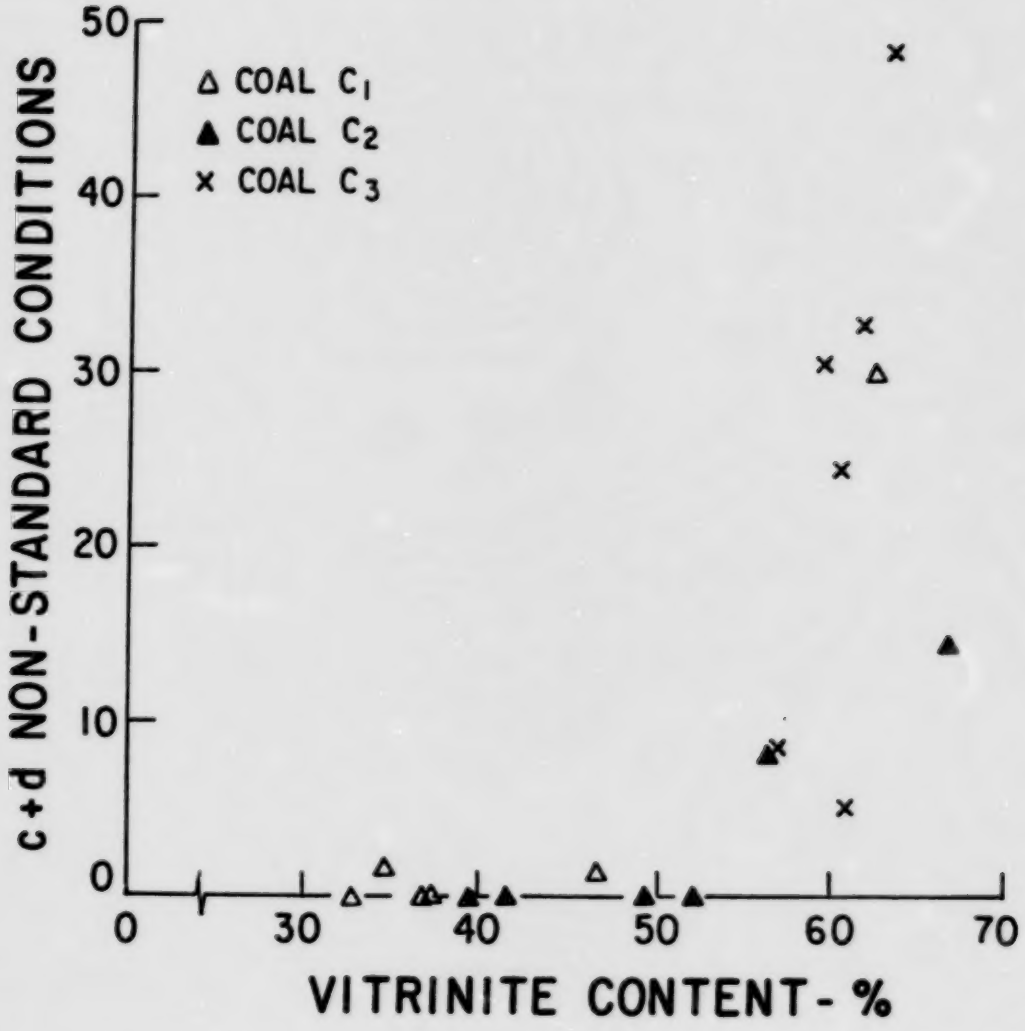


Figure 9 c + d of Western Canadian Coals with the Ruhr Dilatometer at Non-Standard Conditions (4.5°C/min [-8], 4300 psi) as a Function of Vitrinite Level

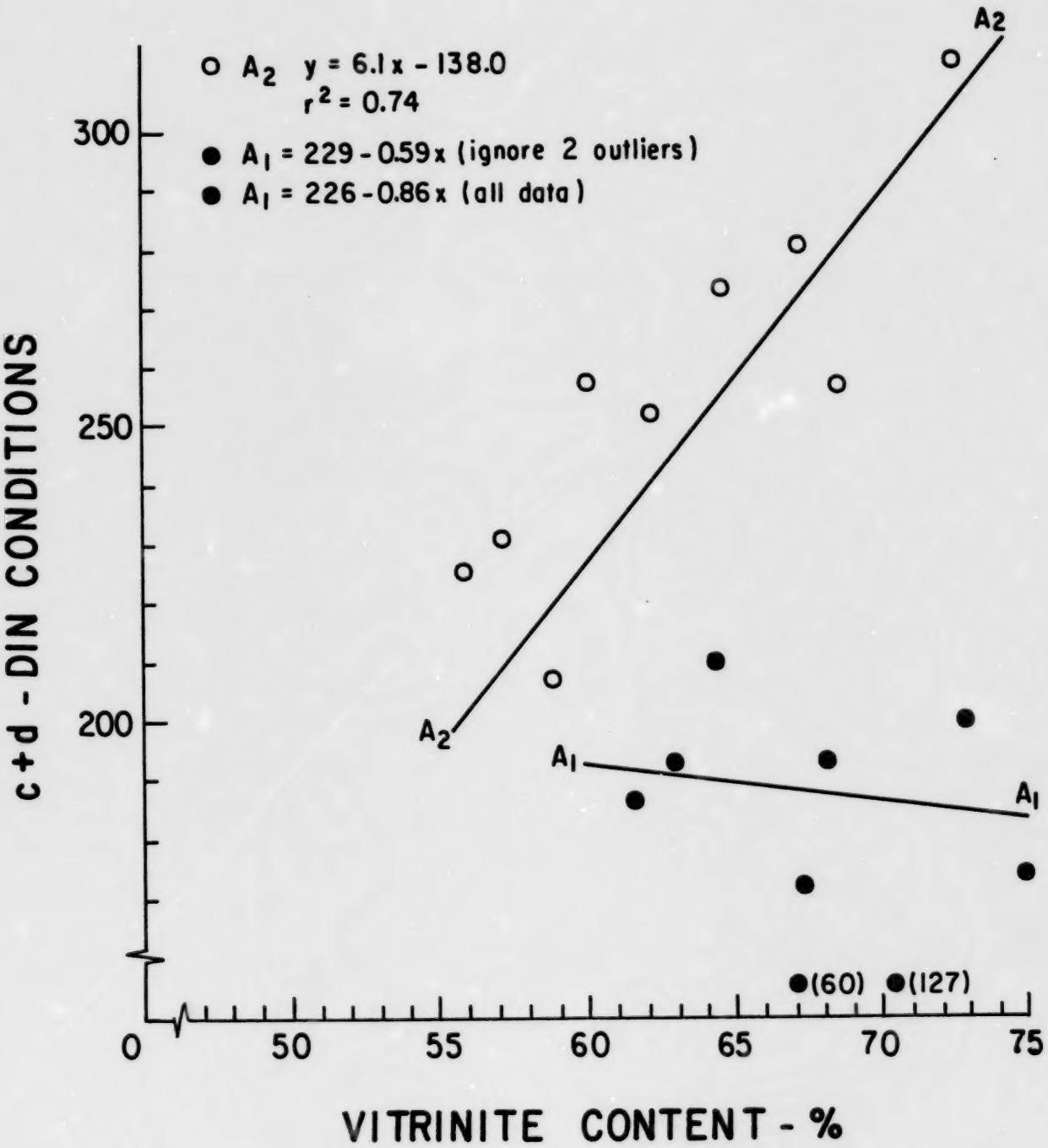


Figure 10 Contraction + Dilatation in a Ruhr Dilatometer for Appalachian Coals at Standard DIN Conditions (3°C/min, [-60], 4300 psi) vs. Vitrinite Content.

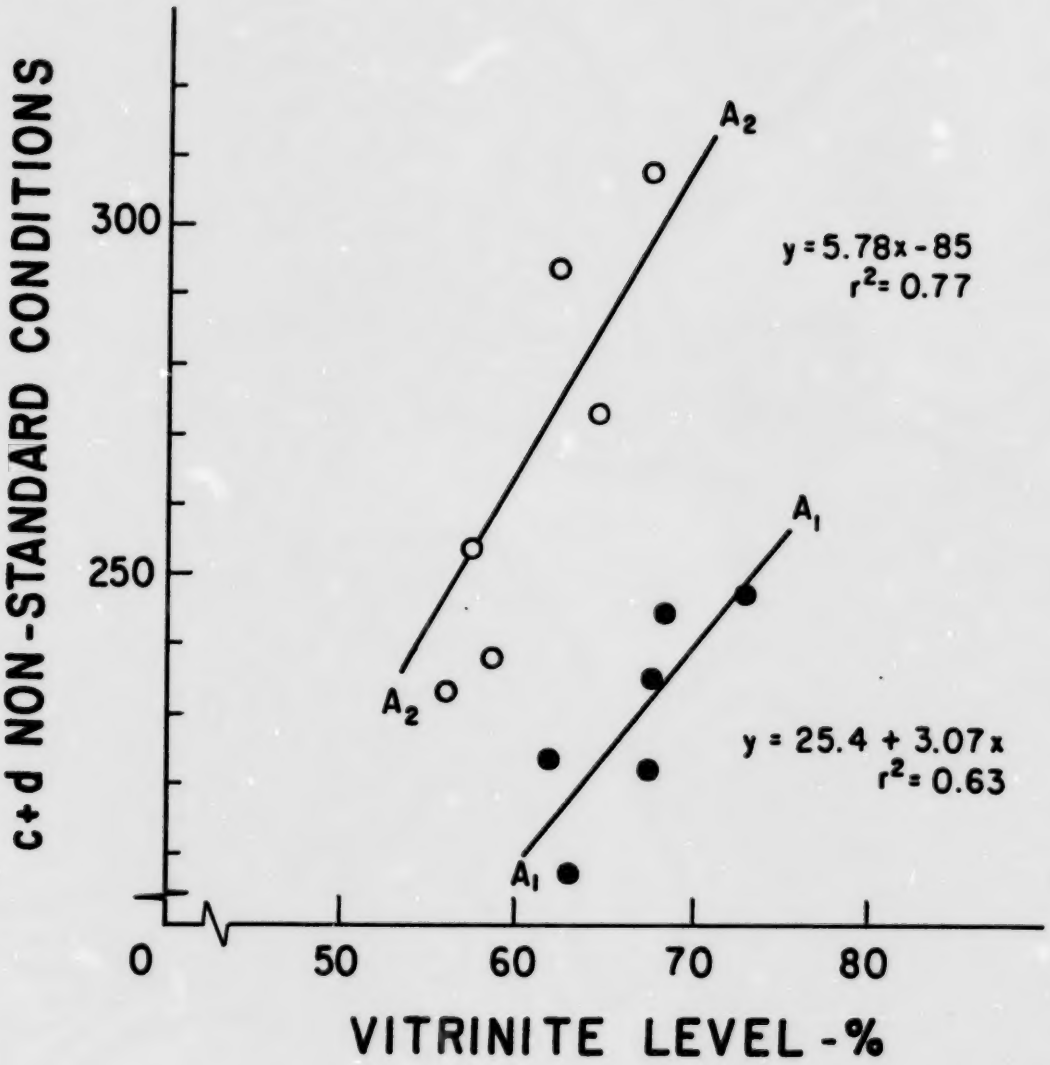


Figure 11 c + d in a Ruhr Dilatometer for Appalachian Coals at Non-Standard Conditions (4.5°C/min, [-8] 4300 psi) as a Function of Vitrinite Level

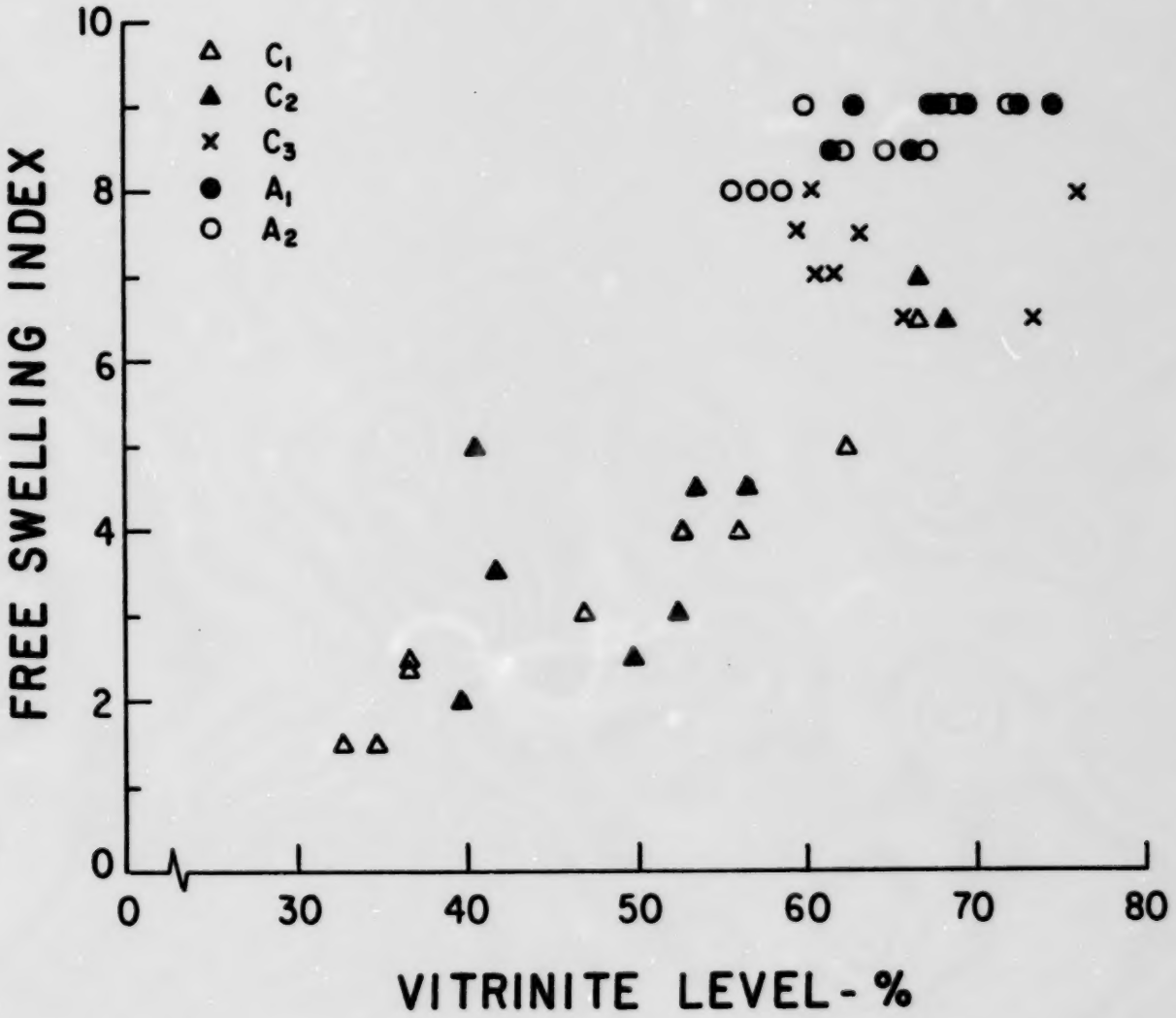


Figure 12 Free Swelling Index v. Vitrinite Content for All Test Coals

VI. INTERPRETATION OF RESULTS

A. Influence of Test Conditions

Starting point for our analysis is that the Western Canadian coals used in this study or Western coals of similar rank and vitrinoid mean reflectance have been tested alone or in blends in CANMET pilot ovens and found to produce coke of reasonable quality. The Appalachian coals tested were coals used for coking.

Against these observations, the rheology measurements reported in the previous section show:

1. The FSI's of the Western Canadian coals indicate coking ability even though dilatometry does not.
2. The rheological properties of Western Canadian coals are significantly dependant on the vitrinite level of the coal.
3. The rheological properties of the two U.S. coals are consistently an order-of-magnitude higher than for the Western Canadian coals, based on dilatometry.
4. Increasing top size to -8 allows dilatation of the high volatile Western Canadian coals, but little apparent change in dilatation properties of the C1 and C2 samples.
5. Increasing top size and heating rate increases dilatation of both Western Canadian and Appalachian coals.

When we compare, as shown in Figure 13, the sum c + d measured under non-standard test conditions to values measured under standard DIN conditions, it is evident that the change from -60 to -8 has had a real, but small effect for th C1 and C2 coals. The effect for the C3, high volatile coal, on the other hand, is large. An increase from 3°C/min to 4.5°C/min significantly changes c + d for the low and medium volatile Western Canadian coals. The influence of rate on the high volatile coal is very much greater. These two different effects of top size and heating rate are apparent for the two Appalachian coals (Figure 14). Top size causes just a small change in c + d ($< 5\%$) whereas heating rate results in

a 30% of pencil length change. Unfortunately, low vitrinite content of the C1 and C2 samples limited the amount of data collected for the samples.

Further consideration of the data, however, reinforces the need to test Western Canadian coals at the large top size. When the minus 8 mesh c + d values for the C1 and C2 samples are grouped in comparison to DIN standard, both at 3°C/min, we note the following:

- 5 of 17 tests produce the same c + d = 0
- 1 of 17 tests gives about the same positive c + d
- 8 of 17 tests show increased c + d for minus 8 mesh
- 3 of 17 tests show DIN conditions as demonstrating better rheology

Although the sum c + d seems minimally higher, there is a substantial change in the individual values of c and d. The higher mesh size reduces the contraction by approximately half (Figure 15) and changes the values of d (Figure 16). These changes are of the order 10% of pencil length for the C1 and C2 samples. Changes are greater for the C3 and Appalachian coals.

In our minds the most sophisticated use of dilatometry involves the G factor derived by Simonis:

$$G = \frac{Ti + Tiii}{2} \times \frac{c + d}{cTiii + dTi}$$

It can be shown that:

- $G > 1$ for $d > 0$ and $|d| > |c|$
- $G = 1$ for $d > 0$ and $|d| = |c|$
- $G < 1$ for $|d| < |c|$
- $G = 0$ for $d < 0$ and $|d| = |c|$

The G factor should be greater than about 0.5 for a coal to be considered to have coking character. Good coking coals have $G > 1$.

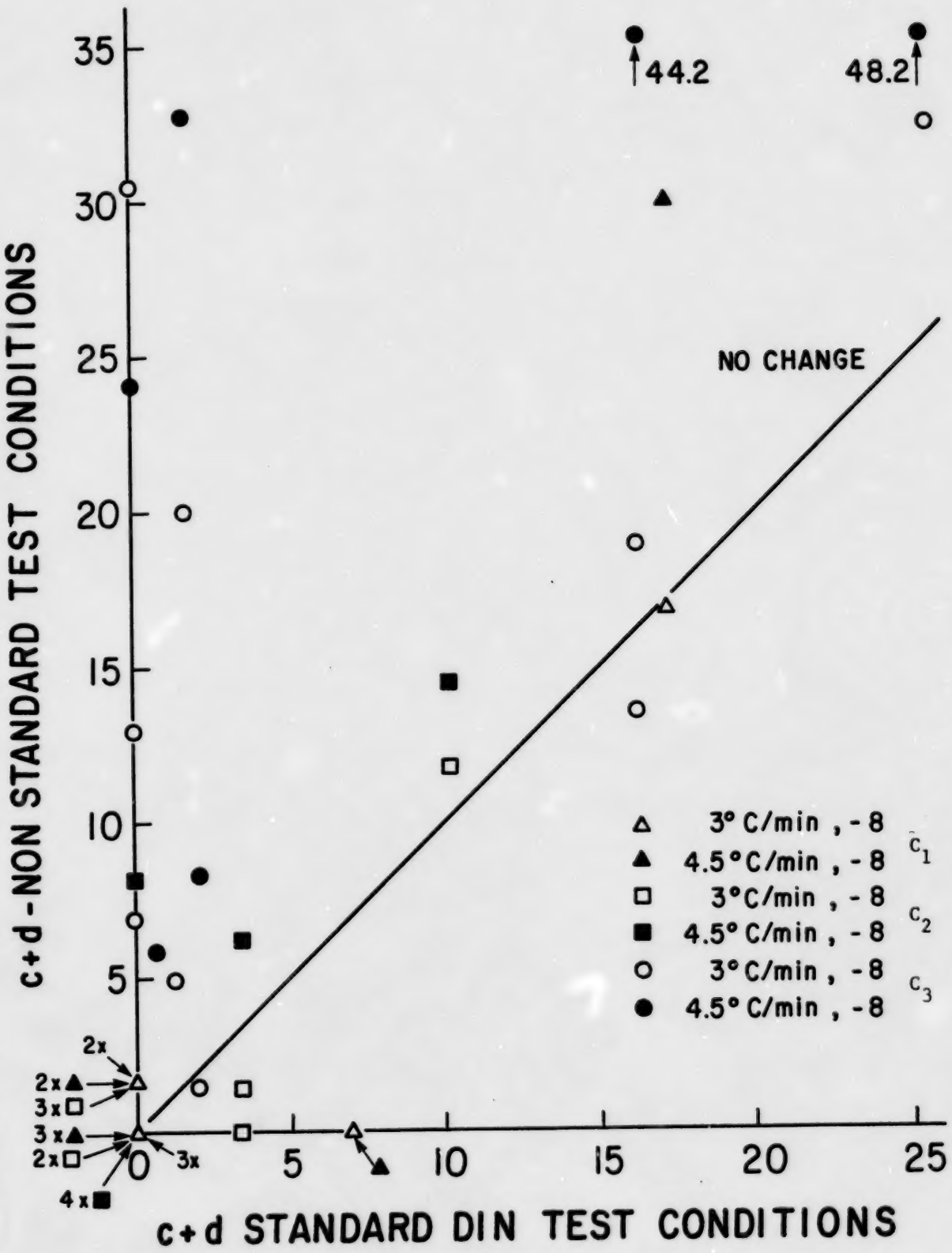


Figure 13. Use of Total Dilatation to Assess the Influence of Test Condition Changes for Western Canadian Samples

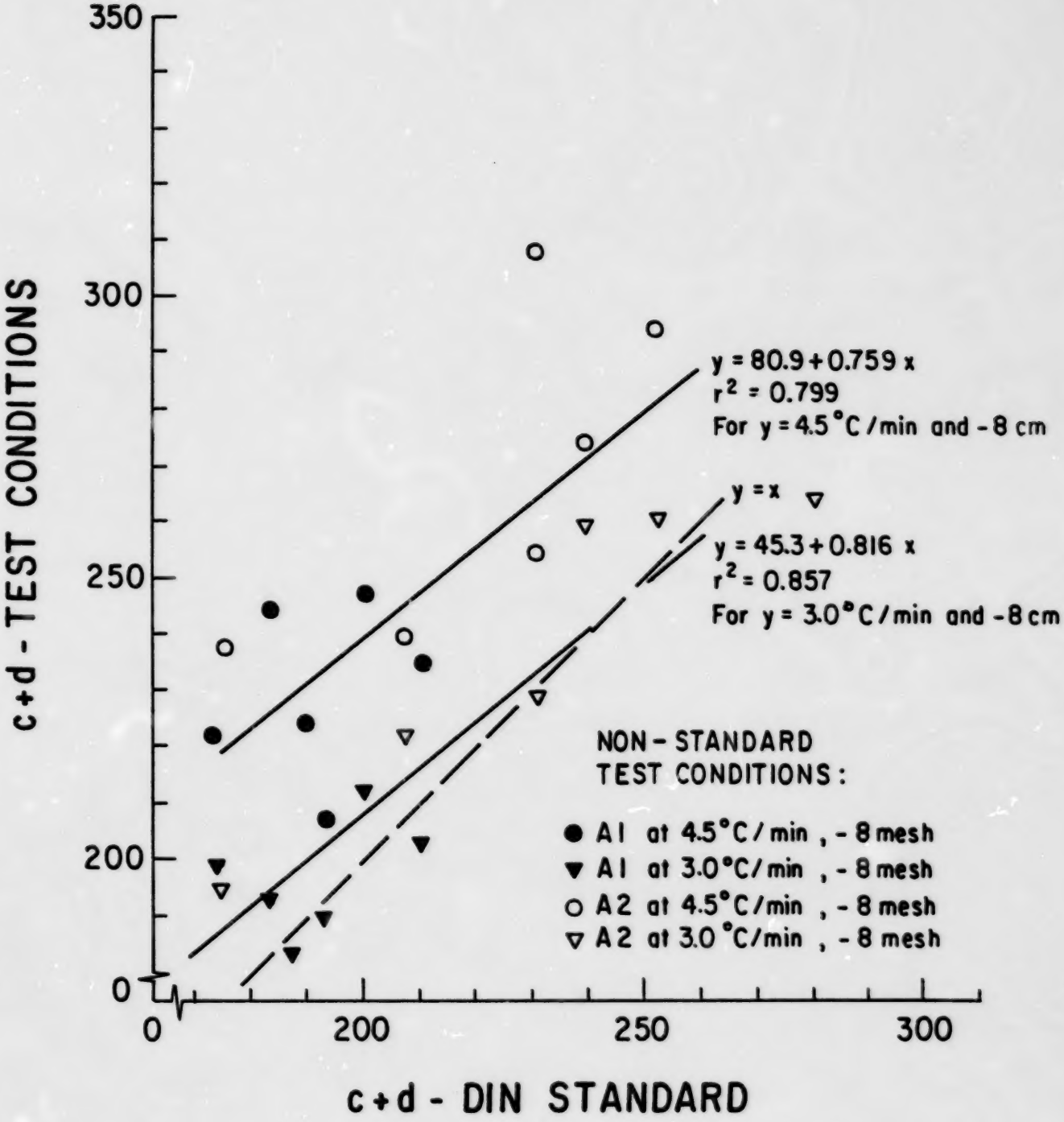

350
300
250
200
0
0
200
250
300
c+d - TEST CONDITIONS
c+d - DIN STANDARD
y = 80.9 + 0.759 x
r² = 0.799
For y = 4.5 °C / min and - 8 cm
y = x
y = 45.3 + 0.816 x
r² = 0.857
For y = 3.0 °C / min and - 8 cm
NON - STANDARD
TEST CONDITIONS :
A1 at 4.5 °C / min , - 8 mesh
A1 at 3.0 °C / min , - 8 mesh
A2 at 4.5 °C / min , - 8 mesh
A2 at 3.0 °C / min , - 8 mesh

Figure 14. Use of Total Dilatation to Assess the Influence of Test Condition Changes for Appalachian Coals

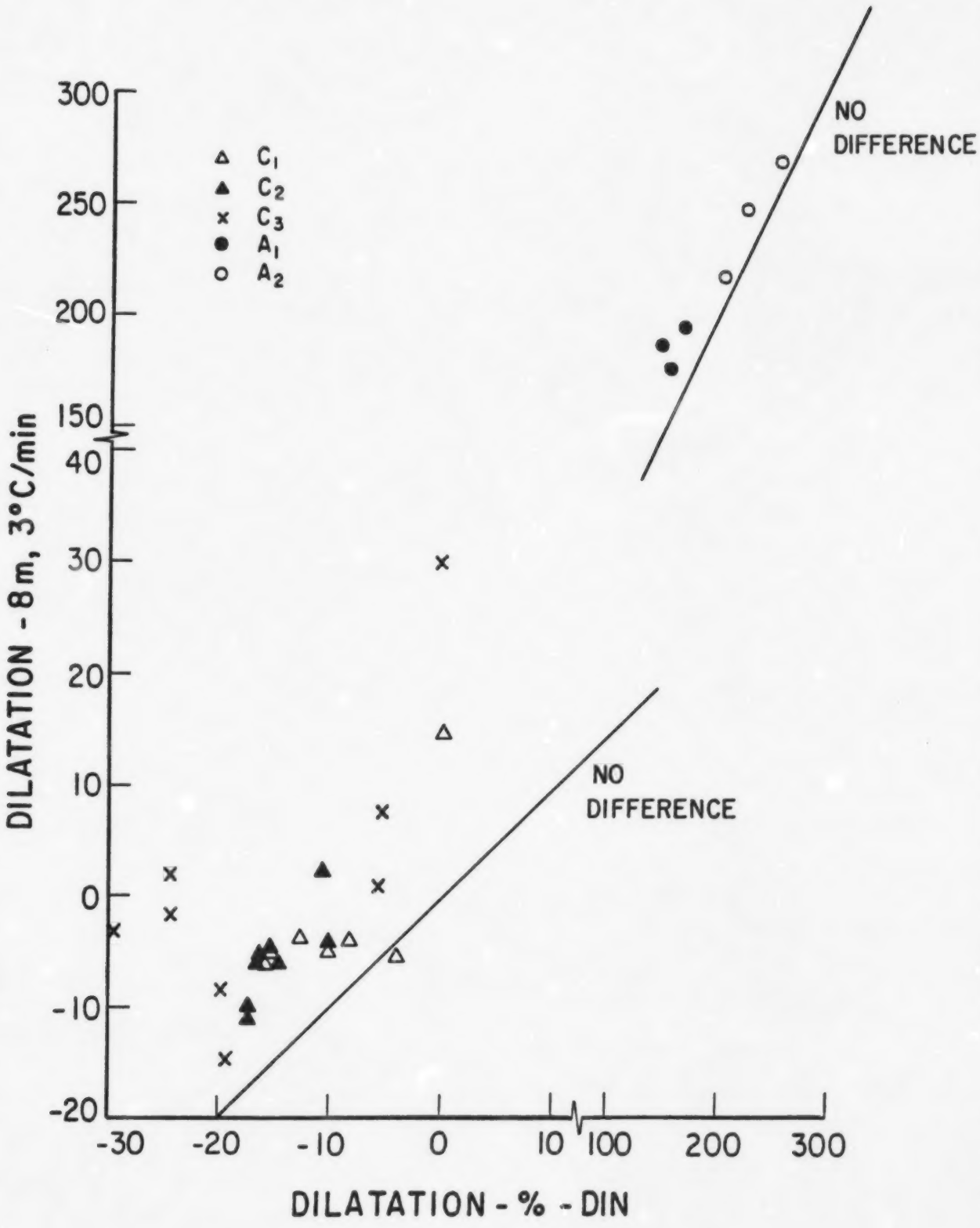


Figure 16. Use of Dilatation to Assess Influence of Test Conditions on Rheology

As illustrated in Figure 17, the higher particle size significantly improved the G-factors of the Western Canadian coals, measured under standard Ruhr conditions

- in 7 of 22 cases, G = 0 at -60 mesh became G > 0.5 at -8 mesh
- in 8 of 22 cases with G ≠ 0, G was increased at -8 mesh
- in 5 of 22 cases, G = 0 was determined at both sizes
- in 1 of 22 cases, G decreased at -8 mesh

Although the same positive effect of high top size on G was noted with the Appalachian coals, the relative impact is minimal compared to Western Canadian coals, especially considering the G = 0 to G 0.5 shift. It seems that a move to larger top size transforms all coals, however, what is significant is that this higher top size places previously marginal coals into the coking coal range.

The top size effect on rheology is well established in the literature. Mackowsky and Wolfe (1966) demonstrated that a top size change from 0.06 mm to 1 mm increased c + d by 50% for a suite of 5 German (carboniferous) coals. The effect was found to be small for prime coking coal, but can be much greater for poorer coals. The G factor was found by Taubert (1978) to depend strongly on top size, but above -40 mesh the influence disappeared. With respect to Western Canadian coals, Leader et al. (1979) observed that the plastic properties of WC coals were improved substantially when oven-sized particles were used in rheological testing. Juranek (1982) observed a distinct improvement in G for WC coal samples that were coarser than the standard particle consist used in rheological testing.

We demonstrated in Figures 13 and 14 that heating rate rather than top size exerts the greatest effect on c + d. Data in Tables C1-4, C2-4, C3-4, A1-4 and A2-4 indicate that the increase in dilatation is primarily responsible for the improvement.

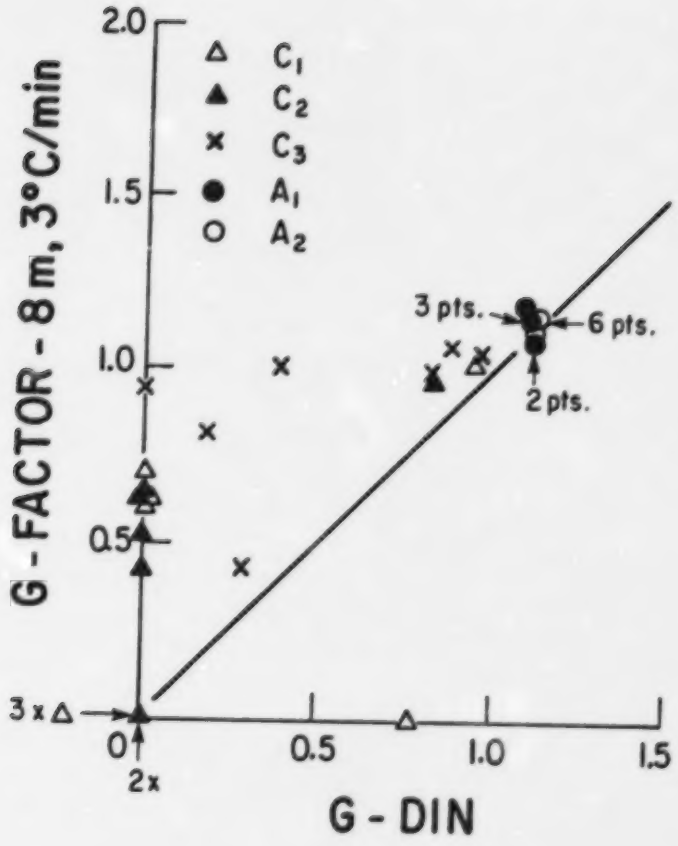


Figure 17. Use of G Factor to Assess the Influence of Sample Top Size on Rheology

Again, the heating rate effect is well known. Figure 18 reproduces measurements of Chermin and Van Krevelen (1957). Berkowitz (1979) discusses the heating rate effect in some detail.

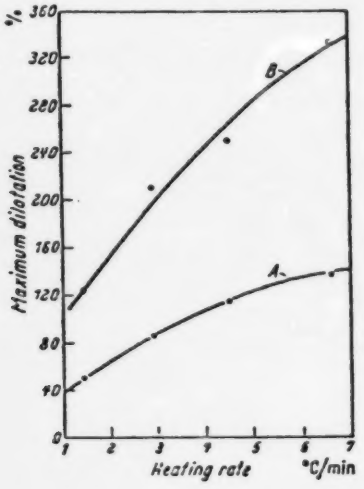


Figure 18: Maximum dilatation as a function of heating rate; vitrinite volatile matter; A 21 percent; B 25 percent (Chermin and Van Krevelen, 1957)

The standard heating rate of 3°C/min goes back to the earliest DIN standards of 1956. The choice appears to be based on either the heating rate at the centre point in a coke oven or perhaps the average heating rate of the charge. The appropriateness of this value is certainly open to discussion. Heating rates along the walls of an oven are substantially greater than 3°C/min. Changes in operating practice since the early 1950's may have also influenced the average heating rate. We have not assembled data on this matter, but a study needs to be done.

In summary, it seems apparent that the closer we approach simulation of coking in rheology test conditions, the better the rheological properties of Western Canadian coals appears and the more compatible their rheological data is with the other coal data. This is certainly the case for top size and is probably true as well for the heating rate.

B. Influence of Mineralogical Composition

It was shown in Section V that a major determinant of Western Canadian coal rheology is vitrinite content. By using regression equations given in Figure 3 - 5, it is possible to predict the maceral analysis of the coals at a constant vitrinite content of 70%. In Figure 19, we have normalized the non-vitrinite plus non-resinite + exinite (i.e. inertinite) fraction to 100%. It is widely recognized that a major characteristic of Western Canadian coals is their high content of semi-fusinite. What Figure 19 shows is that this high semi-fusinite content is at the expense of micrinite, not only vitrinite as previously assumed. The fact that micrinite is usually finely disseminated throughout the vitrinite matrix, while semi-fusinite is much coarser and appears as a distinct large entity may provide a possible explanation of the poor apparent rheology of Western Canadian coals.

The microlithotype analyses (Tables C1-3D, C2-3D, C3-3D, A1-3D and A2-3D in Appendix A, show a dependence on inertinite levels of the free swelling indices (Figure 20). To some extent this reflects an auto correlation of inertinite to vitrinite that is evident in Figure 21. Furthermore, as may be seen in Figure 21, the inertinite-vitrinite data scatter badly. By connecting points of equal FSI on the figure forms lines which slope with respect to the inordinate. Consequently, there must be an FSI dependence on inertinite, even though the major dependence is certainly on vitrinite.

It is our opinion that the order-of-magnitude difference in dilatometric results between Western Canadian and U.S. coals is at least a partial result of the size of the non-vitrinite macerals.

The influence of non reactive macerals on rheology has been known for some time. In a classical paper, van Krevelen et al. (1959) demonstrated dilatation was not simply dependent on the volume fraction of vitrinite. The correction factor to adjust the predicted dilatation to the measured values depended on the inert volume, what the inert is (ash, non reactive macerals, sand, etc.), particle size and shape. Van Krevelen et al.

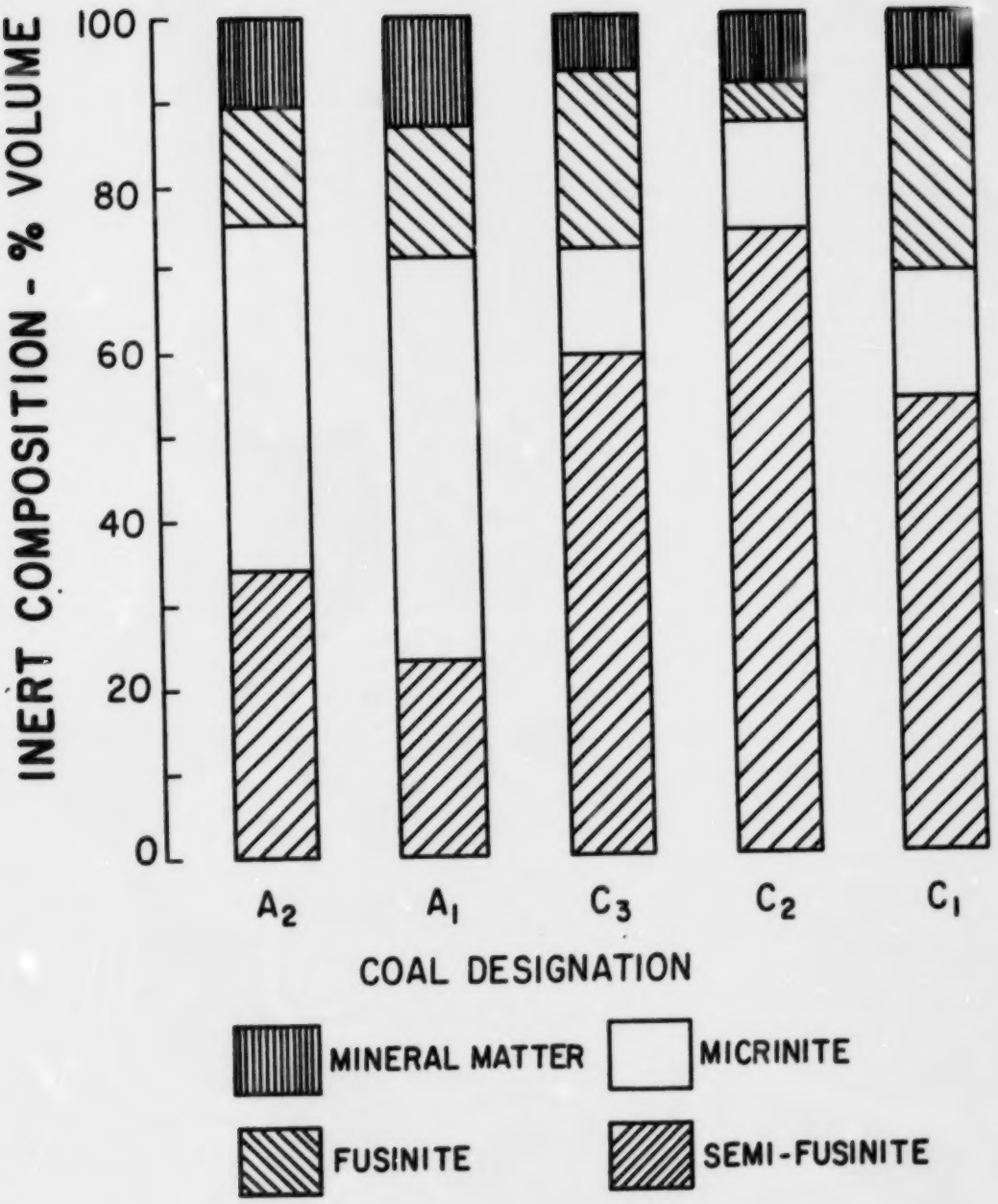


Figure 19. Inert Composition of the Coal Samples at 70% Vitrinite Content

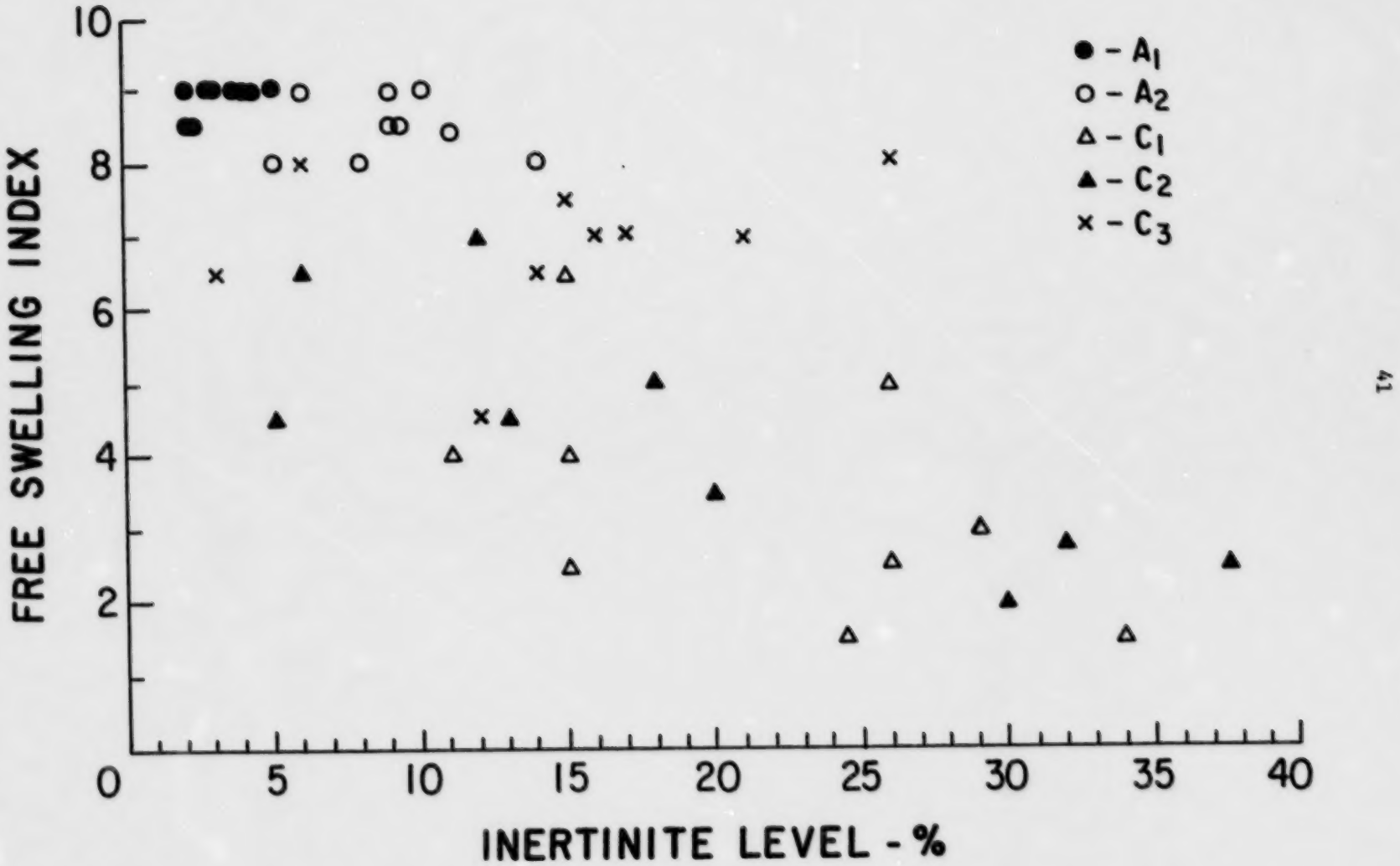


Figure 20 Free Swelling Index vs Inertinite Content

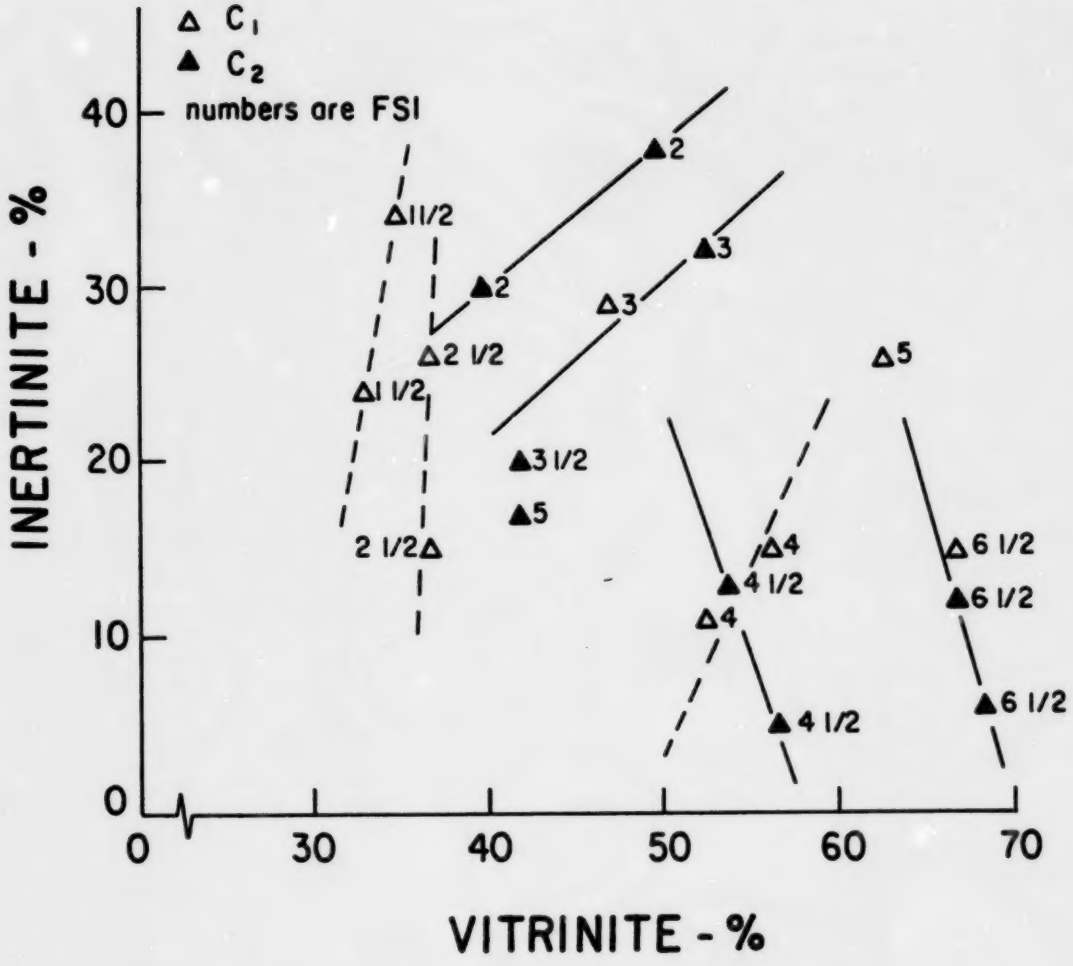


Figure 21. Correlation of FSI with Inertinite vs. Vitrinite Content for the Western Canadian Coals C1 & C2

suggested using total surface area of the inert to estimate its effect on dilatation. Figure 22 reproduces an illustration of the inert and inert particle size influence.

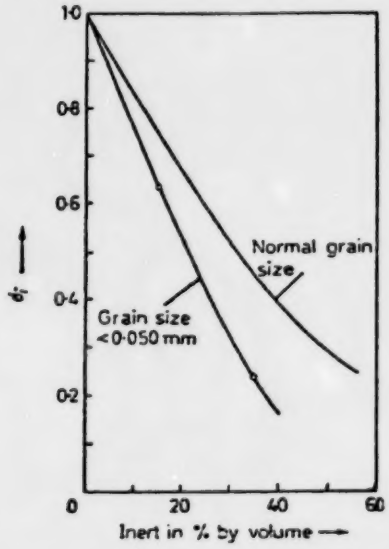


Figure 22: Correction Factor for Dilatation as a Function of Inerts Level and Inert Grain Size (Van Krevelen et al., 1959)

Another example of an inert as well as a particle size effect is the addition of coke breeze to a coke oven charge to control expansion in the coke oven as well as to influence coke properties. Breeze acts as an artificial inert in coking. Besides changing the plastic properties in the oven, coarse coke breeze results in weaker coke.

The coke breeze influence appears to be closer to what we believe explains the Appalachian - Western Canadian difference than the discoveries of van Krevelen and co-workers.

Our hypothesis is that the generally coarse semifusinite macerals act much like coke breeze by interfering with interparticle fusion in the plastic phase.

Mackowsky and Wolff (1966) observation of pore growth in a coal sample under a hot stage microscope has lead to the view that dilatation results from gas development in the interior of a coal particle after the particle

has reached the plastic stage. An equally important mechanism for dilatation must be the fusion of softening particles at contact points creating enclosures which can expand from gas release as the plastic stage proceeds to develop. This many be viewed as an "external" pore development process, whereas the former processes could be termed as "internal" ones. The "external" process probably becomes dominant as particle sizes drop below -60 mesh.

It is our contention that fine crushing results in the release of inerts. These inerts interfere with the fusion process, acting like coke breeze. For a coarser top size, such as -8 mesh, the "external" process becomes less important for dilatation and the coarse inerts (which are not uniformly distributed because vitrinite level depends on cleaning for the Western Canadian coals) have only a diluting effect on the "internal" process.

With the Appalachian coals, the inert material is more finely dispersed so that grinding to -60 top size may not release inert particles which interfere with the external process. Evidentally, the release of inerts and interference with gas entrapment by the fine inerts does not set up until a finer top size than -60 is reached. This is consistent with the known effect of particle size on rheology which become more important for particles <0.1 mm Taubert (1978).

Perhaps the semi-fusinite acts on rheology in the same way as oxidized vitrinite (result of weathering). Dilatation is far more sensitive to weathering than the very small amount of actual oxidation would suggest.

C. Particle Size Influence

Recently Grey (1982) has observed that if reactive macerals are ground to a sufficient degree they become inert in coking. Western Canadian bituminous coals generally are more friable than Appalachian coals of the same rank.

Assuming finely divided coal refers to the -100 mesh fraction, this fraction is compared for the different samples at different stages of crushing in Table 3. Data will be found in Appendix A in Tables C1-1, C2-1, C3-1, A1-1 and A2-1. Measurements at -8 and -20 have been averaged.

Table 3

Comparison of the Weight Fraction of -100 Mesh Sample for the Test Coals

Crushing Level	Coal				
	C1	C2	C3	A1	A2
-4 mesh	4.0	15.9	19.4	4.1	12.7
-8 mesh*	0.3	5.1	11.1	0.4	0.2
-20 mesh	22.2	33.3	36.6	20.7	21.0

* crushed from 4 x 0 cut with -60 fraction removed

There is a large difference in the C3 and A1 samples - both high volatile coals. Unfortunately, 200 and 325 mesh sieves were not used in the characterization. Normally, difference seen at 100 mesh will remain at higher meshes because crushing leads to log normal size distributions. Consequently, it can be argued that crushing the high volatile Western Canadian samples, creates fines that behave as inerts thereby reducing dilatation. A coarser top size than -60 simply reduces the amount of fines in the dilatometer sample.

The argument is more difficult to make for the medium volatile coals, C2 and A2. The difference in the -100 fractions is small for the raw coal crushed to pass 4 mesh, but becomes large for crushing to -20.

VII CONCLUSIONS

Our experiments and analysis permit the following statements to be made.

1. Western Canadian cretaceous coals can be made to exhibit rheology characteristic of coking coals by raising the top size in the dilatometer sample to -8 mesh and increasing the heating rate.

2. Even when non standard test conditions are used, total dilatation of the Western Canadian coals tested remains almost an order of magnitude lower than the dilatation observed for Appalachian coals of the same rank. FSI results for the former coals are 1 to 3 levels below those for the Appalachian coals of the same rank.

3. Western Canadian coal rheology measured in a dilatometer requires a minimum level of approximately 55% vitrinite if the coal is to demonstrate any post contraction swelling.

4. Western Canadian test coals are considerably richer in semi-fusinite and much poorer in micrinite than the Appalachian test samples.

5. An explanation of the poorer rheology is to be found in the relatively higher proportions of semi-fusinite and lower ones of micrinite in the Western Canadian coals. The sizes of these non reactive macerals are very different.

VIII RECOMMENDATIONS FOR FUTURE WORK

1. It has become apparent that rheological tests which more closely simulate coking conditions, especially coal size, is required to accurately rank the coking properties of Western Canadian coals. We recommend that CANMET expedite purchase or fabrication of such an instrument after surveying international developments in this field.

2. We recommend that the ongoing University of Waterloo investigation be tailored to isolate coarse and fine inerts and to validate the effect of each on coal rheology.

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APPENDIX A

RAW DATA

TABLE C1-1A

Sieve Analysis - Raw Coal As Received

Particle Top Size	wt %
[+4]	42.9
[-4]	16.9
[-8]	16.7
[-20]	4.8
[-30]	4.8
[-40]	5.1
[-60]	4.8
[-100]	4.0

Total = 100.0%

TABLE C1-1B

Sieve Analysis - Clean Coal

Particle top size	wt %
> [-4]	35.9
[-4]	15.7
[-8]	20.9
[-20]	4.5
[-30]	4.4
[-40]	5.9
[-60]	4.5
[-100]	8.2
	100.0

TABLE C1-1C

Sieve Analysis - Specific Gravity Fractions

1.4 sg fraction [-4]

Particle Top Size	Wt	Wt %
[-4]	135.4	91.86
[-8]	10.3	6.99
[-20]	0.5	0.34
[-30]	0.7	0.47
[-60]	0.2	0.14
[-100]	0.3	0.20
		Total = 100.00

****

1.4 sg fraction [-8]

Particle Top Size	Wt	Wt %
[-8]	128.3	86.34
[-20]	10.8	7.27
[-30]	7.7	5.18
[-60]	1.0	0.67
[-100]	0.8	0.54
		Total = 100.00

****

1.4 sg fraction [-20]

Particle Top Size	Wt	Wt %
[-20]	32.2	20.54
[-30]	71.3	45.47
[-60]	24.1	15.37
[-100]	29.2	18.62
		Total = 100.00

****

TABLE C1-1C (continued)

1.5 sg fraction [-4]

Particle Top Size	Wt	Wt %
[-4]	230.7	90.61
[-8]	21.9	8.60
[-20]	0.5	0.20
[-30]	0.7	0.27
[-60]	0.3	0.12
[-100]	0.5	0.20

Total = 100.00

****

1.5 sg fraction [-8]

Particle Top Size	Wt	Wt %
[-8]	175.4	96.85
[-20]	4.7	2.59
[-30]	0.7	0.39
[-60]	0.1	0.06
[-100]	0.2	0.11

Total = 100.00

****

1.5 sg fraction [-20]

Particle Top Size	Wt	Wt %
[-20]	39.9	20.57
[-30]	79.7	41.08
[-60]	28.4	14.64
[-100]	46.0	23.71

Total = 100.00

****

TABLE C1-1C (continued)

1.6 sg fraction [-4]

Particle Top Size	Wt	Wt %
[-4]	221.0	92.01
[-8]	17.5	7.29
[-20]	0.4	0.17
[-30]	0.6	0.25
[-60]	0.3	0.12
[-100]	0.4	0.17

Total = 100.01

****

1.6 sg fraction [-8]

Particle Top Size	Wt	Wt %
[-8]	189.1	91.62
[-20]	12.1	5.86
[-30]	3.7	1.79
[-60]	0.6	0.29
[-100]	0.9	0.44

Total = 100.00

****

1.6 sg fraction [-20]

Particle Top Size	Wt	Wt %
[-20]	38.2	18.25
[-30]	88.1	42.09
[-60]	32.1	15.34
[-100]	50.9	24.32

Total = 100.00

****

TABLE C1-2

Chemical Analyses - Western Canadian Coal - C1 L.Vol

Description	Proximate Analysis db%					Ultimate Analysis db%					Mole Ratio				
	Moist.	Ash	Vol.M	Fixed C	F.S.I.	S	C	H	N	O	C	H	N	O	Mcf
1.4 sg															
[-4] top fraction	0.67	5.41	18.38	76.21	2½	0.40	85.96	4.23	0.96	3.04	1.00	0.59	0.010	0.03	1.0067
[-8] top fraction	0.67	4.19	19.91	75.90	5	0.41	86.93	4.41	0.29	3.77	1.00	0.61	0.003	0.03	1.0067
[-20] top fraction	0.67	3.57	20.09	76.34	6½	0.48	87.28	4.38	0.74	3.55	1.00	0.60	0.007	0.03	1.0067
1.5 sg															
[-4] top fraction	0.60	7.73	17.75	74.52	1½	0.31	83.10	3.76	0.10	5.00	1.00	0.54	0.001	0.05	1.006
[-8] top fraction	0.60	6.36	18.51	75.13	3	0.51	84.39	4.03	0.88	3.83	1.00	0.57	0.009	0.03	1.006
[-20] top fraction	0.60	6.02	19.01	74.97	4	0.31	85.87	4.28	0.95	2.57	1.00	0.60	0.009	0.02	1.006
1.6 sg															
[-4] top fraction	0.13	8.87	18.70	72.43	1½	0.28	81.94	3.69	0.82	4.40	1.00	0.54	0.009	0.04	1.0013
[-8] top fraction	0.13	7.28	19.19	73.53	2½	0.35	83.39	3.98	0.23	4.77	1.00	0.57	0.002	0.04	1.0013
[-20] top fraction	0.13	6.73	19.26	74.01	4	0.29	84.10	4.16	1.37	3.35	1.00	0.59	0.014	0.03	1.0013
Clean Coal	0.62	6.58	18.60	73.52	6	0.15									
Raw Coal	0.65	15.62	17.15	65.93	4	0.30									

TABLE C1-3A

Petrography - Western Canadian Coal - C1

Float-Sink

	1.4 sg	1.5 sg	1.6 sg
[-4] top fraction	V-376	V-362	V-346
	SF-356	SF-366	SF-502
	F- 96	F-126	F-103
	M-169	M-146	M- 49
[-8] top fraction	V-640	V-485	V-379
	SF-216	SF-393	SF-355
	F-104	F- 59	F-137
	M- 40	M- 63	M-129
[-20] top fraction	V-681	V-579	V-544
	SF-196	SF-260	SF-240
	F- 77	F- 76	F- 89
	M- 46	M- 85	M-127
Total Vitrinoid	1697	1426	1269
Total Reactives	2742	2706	2695

TABLE C1-3B

Petrography

Specific Gravity	Top Fraction	Reactive Components % Vitrinite	Semi Fusinite	Exinite	Total	Inert Components % Semi Fusinite	Micrinite	Fusinite	Mineral Matter	Total
1.4	[-4]	36.5	17.4	0.0	53.9	17.4	16.4	9.3	3.0	46.1
1.4	[-8]	62.6	10.5	0.0	73.1	10.5	3.9	10.2	2.3	26.9
1.4	[-20]	66.8	6.4	0.0	73.2	12.8	4.5	7.5	2.0	26.8
1.5	[-4]	34.6	17.5	0.0	52.1	17.5	14.0	12.1	4.3	47.9
1.5	[-8]	46.8	18.9	0.0	65.7	18.9	6.1	5.7	3.6	34.3
1.5	[-20]	56.0	12.6	0.0	68.6	12.6	8.2	7.3	3.3	31.4
1.6	[-4]	32.8	23.9	0.0	56.7	23.9	4.7	9.8	4.9	43.3
1.6	[-8]	36.5	17.0	0.0	53.5	17.0	12.4	13.1	4.0	46.5
1.6	[-20]	52.3	11.6	0.0	63.9	11.6	12.2	8.6	3.7	36.1
	C/C	56.4	18.1	0.0	74.5	18.1	0.6	3.2	3.6	25.5
	R/C	42.9	21.6	0.0	64.5	21.6	1.5	3.4	9.0	35.5

Specific Gravity	Top Fraction	Petrographic Indices Mean Reflectance %	Balance Index %	Strength Index %	Stability Index %
1.4	[-4]	1.20	3.16	4.28	33.1
1.4	[-8]	1.23	1.44	4.91	59.9
1.4	[-20]	1.21	1.36	4.73	59.8
1.5	[-4]	1.22	3.58	4.30	29.2
1.5	[-8]	1.24	2.11	4.81	50.6
1.5	[-20]	1.19	1.61	4.52	53.6
1.6	[-4]	1.23	3.06	4.52	37.6
1.6	[-8]	1.24	3.53	4.46	32.1
1.6	[-20]	1.24	2.26	4.83	49.6
	C/C	1.28	1.49	5.35	61.0
	R/C	1.29	2.53	5.30	51.0

TABLE C1-3C

Petrography

Specific Gravity	Top Fraction	Vitrinoid Distribution 0.9	1.0	1.1	1.2	1.3	1.4	1.5
1.4	[-4]	-	17	25	38	20		-
1.4	[-8]	-	1	36	40	23		-
1.4	[-20]	1	7	34	46	12		-
1.5	[-4]	-	1	31	51	17		-
1.5	[-8]	-	1	23	52	24		-
1.5	[-20]	3	22	20	44	11		-
1.6	[-4]	-	3	21	54	22		-
1.6	[-8]	-	-	25	51	24		-
1.6	[-20]	-	2	31	37	28	2	2
	C/C	-	8	22	30	15	15	10
	R/C	-	4	16	36	16	14	14

Specific Gravity	Top Fraction	Maceral Distribution Vit.	Exin.	Res.	S.Fus.	Fus.	Mic
1.4	[-4]	376	-	-	359	96	169
1.4	[-8]	640	-	-	216	104	40
1.4	[-20]	681	-	-	196	77	46
1.5	[-4]	362	-	-	366	126	146
1.5	[-8]	485	-	-	393	59	63
1.5	[-20]	579	-	-	260	76	85
1.6	[-4]	346	-	-	502	103	49
1.6	[-8]	379	-	-	355	137	129
1.6	[-20]	544	-	-	240	89	127
	C/C	585	-	-	376	33	6
	R/C	473	-	-	474	37	16

TABLE C1-3D

Microlithotype Analysis % Vol. - C1

		1.4sg	1.5sg	1.6sg
[-4] top size fraction	Liptate	-	-	-
	Clarite	-	-	-
	Vitrite	18	23	15
	Vitrinertite	40	31	40
	Inertinite	26	34	24
	SF 5		9	13
	F 1		3	2
	M 4		4	2
	Trimacerite	16	12	21
	Durite	-	-	-
[-8] top size fraction	Liptate	-	-	-
	Clarite	-	-	-
	Vitrite	23	12	18
	Vitrinertite	40	44	50
	Inertinite	26	29	15
	SF 12		6	
	F 3		6	
	M 2		3	
	Trimacerite	11	15	17
	Durite	-	-	-
[-20] top size fraction	Liptate	-	-	-
	Clarite	-	-	1
	Vitrite	40	11	25
	Vitrinertite	32	59	48
	Inertinite	15	15	11
	SF 6			
	F 1			
	M 1			
	Trimacerite	13	15	15
	Durite	-	-	-

TABLE C1-4

Dilatometry

Description	Heating Rate	Pressure	Top Size Mesh	Initial Softening Temp °C	Max. Contraction Temp °C	Max. Dilatation Temp °C	Max. Contraction c%	Max. Dilatation d%	c+d	G-factor	FSI
Clean Coal	3°C/min	3000 psi	[-8+]	437	439	-	4.2	-4.2	0.0	*	-
	4.5°C/min	3000 psi	[-8+]	418	461	-	8.3	-8.3	0.0	*	6
	4.5°C/min	3000 psi	[-60+]	424	463	491	16.3	-14.7	1.6	0.41	-
	3°C/min	4300 psi	[-60+]	425	462	489	19.0	-12.0	7.0	0.76	-
Raw Coal	3°C/min	4300 psi	[-60+]	432	473	-	5.8	-5.8	0.0	*	4
Float Sink											
1.4 sg											
[-4] top fraction	3°C/min	3000 psi	[-8+]	445	471	-	6.6	-6.6	0.0	*)	
	4.5°C/min	4300 psi	[-8+]	451	463	-	4.9	-4.9	0.0	*)	2½
	3°C/min	4300 psi	[-60+]	465	475	-	3.3	-3.3	0.0	*)	
[-8] top fraction	3°C/min	3000 psi	[-8+]	451	465	495	1.7	15.2	16.9	1.04)	
	4.5°C/min	4300 psi	[-8+]	438	460	492	7.3	22.7	30.0	1.03)	5
	3°C/min	4300 psi	[-60+]	447	476	511	15.5	1.7	17.2	0.95	
[-20] top fraction	3°C/min	4300 psi	[-60+]	436	462	519	18.0	8.2	26.2	0.97	6½
1.5 sg											
[-4] top fraction	3°C/min	3000 psi	[-8+]	446	505	540	6.5	-4.8	1.7	0.61)	
	4.5°C/min	4300 psi	[-8+]	455	500	535	5.0	-3.3	1.7	0.72)	1½
	3°C/min	4300 psi	[-60+]	460	492	-	8.3	-8.3	0.0	*)	
[-8] top fraction	3°C/min	3000 psi	[-8+]	441	452	-	5.0	-5.0	0.0	*)	
	4.5°C/min	4300 psi	[-8+]	444	470	490	4.9	-3.3	1.6	0.80)	3
	3°C/min	4300 psi	[-60+]	445	523	-	16.3	-16.3	0.0	*)	
[-20] top fraction	3°C/min	4300 psi	[-60+]	438	550	-	17.9	-17.9	0.0	*	4
1.6 sg											
[-4] top fraction	3°C/min	3000 psi	[-8+]	445	462	-	4.8	-4.8	0.0	*)	
	4.5°C/min	4300 psi	[-8+]	456	470	-	4.9	-4.9	0.0	*)	1½
	3°C/min	4300 psi	[-60+]	453	523	-	9.9	-9.9	0.0	*)	

TABLE C1-4 (continued)

[-8] top fraction	3°C/min	3000 psi	[-8+]	436	468	487	6.7	-5.0	1.7	0.72)	
	4.5°C/min	4300 psi	[-8+]	445	459	-	5.0	-5.0	0.0	*)	2½
	3°C/min	4300 psi	[-60+]	447	484	-	15.5	-15.5	0.0	*)	
[-20] top fraction	3°C/min	4300 psi	[-60+]	446	515	543	13.2	-11.6	1.6	0.40	4

TABLE C2-1A

Sieve Analysis - Raw Coal As Received

Particle Top Size	wt %
[+4]	24.7
[-4]	12.4
[-8]	18.8
[-20]	6.1
[-30]	6.1
[-40]	8.6
[-60]	7.2
[-100]	15.9

Total = 99.8%

TABLE C2-1B

Sieve Analysis - Clean Coal

Particle top size	wt %
> [-4]	15.2
[-4]	9.6
[-8]	14.2
[-20]	6.8
[-30]	8.4
[-40]	11.4
[-60]	10.1
[-100]	24.3
	100.0

TABLE C2-1C

Sieve Analysis - Specific Gravity Fractions

1.4 sg fraction [-4] Sample wt = 74.1g

Particle Top Size	Wt	Wt %
[-4]	61.1	82.50
[-8]	4.5	6.13
[-20]	1.0	1.31
[-30]	1.9	2.56
[-60]	1.7	2.29
[-100]	3.9	5.21
		Total = 100.00

****

1.4 sg fraction [-8] Sample wt = 79.0g

Particle Top Size	Wt	Wt %
[-8]	63.6	80.51
[-20]	3.9	4.94
[-30]	5.5	6.96
[-60]	2.2	2.78
[-100]	3.8	4.81
		Total = 100.00

****

1.4 sg fraction [-20] Sample wt = 73.5g

Particle Top Size	Wt	Wt %
[-20]	8.4	11.43
[-30]	26.8	36.46
[-60]	13.8	18.78
[-100]	24.5	33.33
		Total = 100.00

****

TABLE C2-1C (continued)

1.5 sg fraction [-4] Sample wt = 194.5g

Particle Top Size	Wt	Wt %
[-4]	160.0	82.26
[-8]	16.3	8.38
[-20]	3.0	1.54
[-30]	7.0	3.60
[-60]	3.0	1.54
[-100]	5.2	2.67

Total = 99.99

****

1.5 sg fraction [-8] Sample wt = 182.9g

Particle Top Size	Wt	Wt %
[-8]	130.2	71.19
[-20]	16.8	9.19
[-30]	18.6	10.17
[-60]	6.9	3.77
[-100]	10.4	5.69

Total = 100.01

****

1.5 sg fraction [-20] Sample wt = 241.7g

Particle Top Size	Wt	Wt %
[-20]	29.0	12.00
[-30]	83.7	34.63
[-60]	53.7	22.22
[-100]	75.3	31.15

Total = 100.00

****

TABLE C2-1C (continued)

1.6 sg fraction [-4] Sample wt = 204.9g

Particle Top Size	Wt	Wt %
[-4]	178.0	86.87
[-8]	10.1	4.93
[-20]	1.9	0.93
[-30]	4.2	2.05
[-60]	6.1	2.98
[-100]	4.6	2.24

Total = 100.00

****

1.6 sg fraction [-8] Sample wt = 183.8g

Particle Top Size	Wt	Wt %
[-8]	144.5	78.62
[-20]	13.7	7.45
[-30]	12.5	6.80
[-60]	4.4	2.39
[-100]	8.70	4.73

Total = 99.99

****

1.6 sg fraction [-20] Sample wt = 252.4g

Particle Top Size	Wt	Wt %
[-20]	30.00	11.89
[-30]	85.9	34.03
[-60]	46.7	18.50
[-100]	89.8	35.58

Total = 100.00

****

TABLE C2-2

Chemical Analyses - Western Canadian Coal - C2 L. Vol

Description	Proximate Analysis db% Moist.	Ash	Vol.M	Fixed C	F.S.I.	Ultimate Analysis db% S	C	H	N	O	Mole Ratio C	H	N	O	Mcf
1.4 sg															
[-4] top fraction	0.73	6.31	21.07	72.62	4½	0.21	83.30	4.04	1.17	4.97	1.00	0.58	0.012	0.04	1.0074
[-8] top fraction	1.01	4.96	21.84	73.20	7	0.35	84.55	3.80	1.12	5.22	1.00	0.54	0.011	0.05	1.0101
[-20] top fraction	1.33	5.30	21.56	73.14	6½	0.36	84.06	4.39	2.45	3.44	1.00	0.63	0.025	0.03	1.0133
1.5 sg															
[-4] top fraction	0.58	10.46	19.80	69.74	2½	0.66	78.08	3.98	1.11	5.71	1.00	0.61	0.012	0.05	1.0059
[-8] top fraction	0.82	9.28	20.29	70.43	3	0.60	80.73	4.13	1.08	4.18	1.00	0.61	0.011	0.04	1.0082
[-20] top fraction	1.79	8.07	20.93	71.00	4½	0.66	81.71	4.18	0.75	4.63	1.00	0.61	0.008	0.04	1.0180
1.6 sg															
[-4] top fraction	0.60	11.93	19.45	68.62	2	0.56	77.03	3.79	0.51	6.18	1.00	0.59	0.006	0.06	1.0061
[-8] top fraction	0.78	9.83	20.14	70.03	3½	0.44	79.55	4.27	0.36	5.55	1.00	0.64	0.004	0.05	1.0078
[-20] top fraction	1.49	8.43	20.88	70.69	5	0.33	82.26	4.27	1.53	3.18	1.00	0.62	0.016	0.03	1.0150
Clean Coal	0.60	9.70	20.80	68.40	7½	0.30									
Raw Coal	0.91	18.24	17.80	62.15	4	0.30									

TABLE C2-3A

Petrography - Western Canadian Coal - C2

Float-Sink

	1.4 sg	1.5 sg	1.6 sg
[-4] top fraction	V-586	V-526	V-425
	SF-290	SF-354	SF-352
	F-86	F-66	F-161
	M-38	M-54	M-62
[-8] top fraction	V-688	V-550	V-440
	SF-222	SF-332	SF-292
	F-36	F-99	F-190
	M-54	M-19	M-78
[-20] top fraction	V-702	V-562	V-427
	SF-232	SF-298	SF-390
	F-18	F-94	F-116
	M-48	M-46	M-67
Total Vitrinoid	1976	1638	1292
Total Reactives	2860	2881	2793

TABLE C2-3B

Petrography

Specific Gravity	Top Fraction	Reactive Components %				Inert Components %				
		Vitrinite	Semi Fusinite	Exinite	Total	Semi Fusinite	Micrinite	Fusinite	Mineral Matter	Total
1.4	[-4]	56.5	14.0	0.0	70.5	14.0	3.7	8.3	3.5	29.5
1.4	[-8]	66.9	10.8	0.0	77.7	10.8	5.3	3.5	2.7	22.3
1.4	[-20]	68.1	11.3	0.0	79.4	11.3	4.7	1.7	2.9	20.6
1.5	[-4]	49.5	16.6	0.0	66.1	16.6	5.1	6.2	6.0	33.9
1.5	[-8]	52.2	15.7	0.0	67.9	15.7	1.8	9.4	5.2	32.1
1.5	[-20]	53.6	14.2	0.0	67.8	14.2	4.4	9.0	4.6	32.2
1.6	[-4]	39.6	16.4	0.0	56.0	16.4	5.8	15.0	6.8	44.0
1.6	[-8]	41.5	13.8	0.0	55.3	13.8	7.4	18.0	5.5	44.7
1.6	[-20]	40.6	18.6	0.0	59.2	18.6	6.4	11.1	4.7	40.8
	C/C	47.8	19.1	0.0	66.9	19.1	7.4	1.2	5.4	33.1
	R/C	44.7	19.0	0.0	63.7	19.0	4.8	1.9	10.6	36.3

Specific Gravity	Top Fraction	Petrographic Indices			
		Mean Reflectance %	Balance Index %	Strength Index %	Stability Index %
1.4	[-4]	1.15	1.36	4.40	56.1
1.4	[-8]	1.18	0.99	4.61	61.4
1.4	[-20]	1.16	0.85	4.42	60.5
1.5	[-4]	1.16	1.73	4.43	51.7
1.5	[-8]	1.18	1.58	4.42	53.1
1.5	[-20]	1.15	1.51	4.35	53.0
1.6	[-4]	1.19	2.82	4.17	34.8
1.6	[-8]	1.18	2.76	4.10	34.3
1.6	[-20]	1.20	2.51	4.37	41.9
	C/C	1.19	2.18	5.27	53.5
	R/C	1.18	2.00	4.48	48.0

TABLE C2-3C

Petrography

Specific Gravity	Top Fraction	Vitrinoid Distribution 0.9	1.0	1.1	1.2	1.3	1.4
1.4	[-4]	2	18	56	22	2	-
1.4	[-8]	-	8	56	32	4	-
1.4	[-20]	4	20	44	32	-	-
1.5	[-4]	2	18	44	28	8	-
1.5	[-8]	4	24	32	32	8	-
1.5	[-20]	4	20	56	16	4	-
1.6	[-4]	-	8	36	56	-	-
1.6	[-8]	-	12	48	40	-	-
1.6	[-20]	-	8	36	48	8	-
	C/C	6	13	25	47	9	
	R/C	-	8	54	28	9	1

Specific Gravity	Top Fraction	Maceral Distribution Vit.	Exin.	Res.	S.Fus.	Fus.	Mic
1.4	[-4]	586	-	-	290	86	38
1.4	[-8]	688	-	-	222	36	54
1.4	[-20]	702	-	-	232	18	48
1.5	[-4]	526	-	-	354	66	54
1.5	[-8]	550	-	-	332	99	19
1.5	[-20]	562	-	-	298	94	46
1.6	[-4]	425	-	-	352	161	62
1.6	[-8]	440	-	-	292	190	78
1.6	[-20]	427	-	-	390	116	67
	C/C	506	-	-	403	13	78
	R/C	500	-	-	425	21	54

TABLE C2-3D

Microlithotype Analysis % Vol. - C2

		1.4sg	1.5sg	1.6sg
[-4] top size fraction	Liptate	-	-	-
	Clarite	3	-	-
	Vitrite	28	8	8
	Vitrinertite	52	45	51
	Inertinite	5	38	30
	SF	1	17	14
	F	1	10	12
	M	2	1	1
	Trimacerite	12	9	11
	Durite	-	-	-
[-8] top size fraction	Liptate	-	-	-
	Clarite	-	-	-
	Vitrite	29	16	18
	Vitrinertite	56	42	52
	Inertinite	12	32	20
	SF	8	15	16
	F	1	11	2
	M	3	1	1
	Trimacerite	3	10	10
	Durite	-	-	-
[-20] top size fraction	Liptate	-	-	-
	Clarite	-	-	-
	Vitrite	36	25	29
	Vitrinertite	57	57	42
	Inertinite	6	13	18
	SF		7	10
	F		-	4
	M		1	-
	Trimacerite	1	5	11
	Durite	-	-	-

TABLE C2-4

Dilatometry

Description	Heating Rate	Pressure	Top Size Mesh	Initial Softening Temp °C	Max. Contraction Temp °C	Max. Dilatation Temp °C	Max. Contraction c%	Max. Dilatation d%	c+d	G-factor	FSI
Clean Coal	3°C/min	3000 psi	[-8+]	420	483	512.5	11.3	-9.7	1.6	0.43	-
	4.5°C/min	4300 psi	[-8+]	426	462	479	11.1	-4.8	6.3	0.87	-
	3°C/min	4300 psi	[-60+]	420	464.5	475	21.3	-18.0	3.3	0.58	-
	3°C/min	4300 psi	[-8+]	422.5	453	-	10.9	-10.9	0.0	*	-
Float Sink											
1.4 sg											
[-4] top fraction	3°C/min	3000 psi	[-8+]	428	482	514	6.6	-4.9	1.7	0.62)	
	4.5°C/min	4300 psi	[-8+]	431	462	488	9.8	-1.6	8.2	0.92)	4½
	3°C/min	4300 psi	[-60+]	436	473	-	15.0	-15.0	0.0	*)	
[-8] top fraction	3°C/min	3000 psi	[-8+]	428	456	521	8.4	3.4	11.8	0.96)	
	4.5°C/min	4300 psi	[-8+]	427	458	494	4.8	9.7	14.5	1.03)	7
	3°C/min	4300 psi	[-60+]	428	463	480	20.3	-10.2	10.1	0.85)	
[-20] top fraction	3°C/min	4300 psi	[-60+]	428	459	-	18.5	-18.5	0.0	*	6½
1.5 sg											
[-4] top fraction	3°C/min	3000 psi	[-8+]	436	484	509	6.6	-4.9	1.7	0.66)	
	4.5°C/min	4300 psi	[-8+]	444	462	-	4.8	-4.8	0.0	*)	2½
	3°C/min	4300 psi	[-60+]	449	492	-	9.9	-9.9	0.0	*)	
[-8] top fraction	3°C/min	3000 psi	[-8+]	429	499	528	8.1	-6.4	1.7	0.53)	
	4.5°C/min	4300 psi	[-8+]	448	473	-	4.8	-4.8	0.0	*)	3
	3°C/min	4300 psi	[-60+]	440	502	-	15.2	-15.2	0.0	*)	
[-20] top fraction	3°C/min	4300 psi	[-60+]	441	495	-	13.4	-13.4	0.0	*	4½
1.6 sg											
[-4] top fraction	3°C/min	3000 psi	[-8+]	428	446	-	6.6	-6.6	0.0	*)	
	4.5°C/min	4300 psi	[-8+]	442	500	-	6.7	-6.7	0.0	*)	2
	3°C/min	4300 psi	[-60+]	435	509	-	13.6	-13.6	0.0	*)	
[-8] top fraction	3°C/min	3000 psi	[-8+]	435	453	-	6.6	-6.6	0.0	*)	
	4.5°C/min	4300 psi	[-8+]	435	465	-	8.2	-8.2	0.0	*)	3½
	3°C/min	4300 psi	[-60+]	435	539	-	16.4	-16.4	0.0	*)	
[-20] top fraction	3°C/min	4300 psi	[-60+]	430	538	-	20.0	-20.0	0.0	*	5

TABLE C3-1A

Sieve Analaysis - Raw Coal As Received

Particle Top Size	wt %
[+4]	8.6
[-4]	11.5
[-8]	22.8
[-20]	8.2
[-30]	7.9
[-40]	11.9
[-60]	9.7
[-100]	19.4

Total = 100.0%

TABLE C3-1C

Sieve Analysis - Specific Gravity Fractions

1.4 sg fraction [-4] Sample wt = 36.4g

Particle Top Size	Wt	Wt %
[+4]	0.0	0.00
[-4]	30.5	83.79
[-8]	5.1	14.01
[-20]	0.2	0.55
[-30]	0.4	1.10
[-60]	0.1	0.27
[-100]	0.1	0.27

Total = 99.99

****

1.4 sg fraction [-8] Sample wt = 73.5g

Particle Top Size	Wt	Wt %
[-8]	67.7	92.11
[-20]	4.9	6.67
[-30]	0.6	0.82
[-60]	0.2	0.27
[-100]	0.1	0.14

Total = 100.01

****

1.4 sg fraction [-20] Sample wt = 39.1g

Particle Top Size	Wt	Wt %
[-20]	4.5	11.51
[-30]	14.0	35.81
[-60]	6.5	16.62
[-100]	14.1	36.06

Total = 100.00

****

TABLE C3-1C (continued)

1.5 sg fraction [-4] Sample wt = 71.2g

Particle Top Size	Wt	Wt %
[-4]	56.9	80.03
[-8]	9.4	13.20
[-20]	1.1	1.53
[-30]	0.7	0.99
[-60]	0.9	1.21
[-100]	2.2	3.04

Total = 100.00

****

1.5 sg fraction [-8] Sample wt = 19.9g

Particle Top Size	Wt	Wt %
[-8]	14.6	73.37
[-20]	1.9	9.55
[-30]	1.6	8.04
[-60]	0.5	2.51
[-100]	1.3	6.53

Total = 100.00

****

1.5 sg fraction [-20] Sample wt = 76.9g

Particle Top Size	Wt	Wt %
[-20]	8.2	10.66
[-30]	24.6	31.99
[-60]	12.7	16.52
[-100]	31.4	40.83

Total = 100.00

****

TABLE C3-1C (continued)

1.6 sg fraction [-4] Sample wt = 89.7g

Particle Top Size	Wt	Wt %
[-4]	9.90	11.21
[-8]	22.65	25.64
[-20]	25.50	28.86
[-60]	8.65	9.7
[-100]	21.65	24.50

Total = 100.00

****

1.6 sg fraction [-8] Sample wt = 82.25g

Particle Top Size	Wt	Wt %
[-8]	23.65	28.17
[-20]	29.20	34.78
[-60]	8.70	10.36
[-100]	22.40	26.68

Total = 99.99

****

1.6 sg fraction [-20] Sample wt = 89.3g

Particle Top Size	Wt	Wt %
[-20]	46.00	52.48
[-60]	12.80	14.60
[-100]	28.85	32.92

Total = 100.00

****

TABLE C3-2

Chemical Analyses - Western Canadian Coal C3 Hi.Vol

Description	Proximate Analysis db% Moist.	Ash	Vol.M	Fixed C	F.S.I.	Ultimate Analysis db% S	C	H	N	O	Mole Ratio C : H : N : O	Mcf
1.4 sg												
[-4] top fraction	1.82	4.83	28.53	66.64	7	0.70	82.88	4.90	1.03	5.66	1.00 0.71 0.01 0.05	1.018
[-8] top fraction	2.12	4.12	31.44	64.44	7½	0.28	83.57	5.05	1.51	5.47	1.00 0.73 0.02 0.05	1.021
[-20] top fraction	4.59	3.62	29.29	67.09	8	0.19	84.39	5.11	1.15	5.54	1.00 0.73 0.01 0.05	1.046
1.5 sg												
[-4] top fraction	1.68	7.06	28.52	64.42	4½	2.13	81.27	4.76	0.98	3.80	1.00 0.70 0.01 0.04	1.017
[-8] top fraction	3.86	4.54	27.95	67.51	7	1.26	83.98	5.02	1.40	3.80	1.00 0.72 0.01 0.03	1.039
[-20] top fraction	6.10	4.52	28.82	66.66	6½	0.38	83.03	4.95	0.98	6.14	1.00 0.72 0.01 0.06	1.061
1.6 sg												
[-4] top fraction	2.62	4.93	30.00	65.07	7½	1.09	84.82	5.03	1.45	2.68	1.00 0.71 0.01 0.02	1.026
[-8] top fraction	2.36	5.14	29.28	65.58	8	1.00	81.79	4.82	1.62	5.63	1.00 0.71 0.02 0.05	1.024
[-20] top fraction	1.92	6.14	29.37	64.49	6½	0.27	80.74	4.72	1.15	6.98	1.00 0.70 0.01 0.06	1.019
Raw Coal	1.21	11.03	30.16	58.81	7½	0.42						1.012

TABLE C3-3A

Petrography - Western Canadian Coal - C3

Float-Sink

	1.4 sg		1.5 sg		1.6 sg	
[-4] top fraction	314V	636V	303V	596V	320V	611V
	322V	659R	293V	633R	291V	626R
	11E	37M	18E	53M	8E	53M
	12E		19E		7E	
[-8] top fraction	322V	648V	315V	626V	307V	622V
	326V	667R	311V	652V	315V	649R
	10E	55M	17E	30M	9E	56M
	9E		9E		18E	
[-20] top fraction	397V	778V	373V	753V	344V	682V
	381V	805R	380V	763R	338V	708R
	13E	38M	6E	20M	12E	45M
	14E		4E		14E	
Total Vitrinoid	2062		1975		1915	
Total Reactives	2131		2048		1983	

V - Vitrinoid
E - Exinoid
R - Reactives

TABLE C3-3B

Petrography

Specific Gravity	Top Fraction	Reactive Components %				Inert Components %				
		Vitrinite	Semi-Fusinite	Exinite	Total	Semi-Fusinite	Micrinite	Fusinite	Mineral Matter	Total
1.4	[-4]	61.8	6.2	2.2	70.2	12.5	3.6	10.8	2.9	29.8
1.4	[-8]	63.3	6.1	1.9	71.3	12.2	5.4	8.8	2.3	28.7
1.4	[-20]	76.2	4.4	2.6	83.2	8.8	3.7	2.3	2.0	16.8
1.5	[-4]	57.0	10.6	3.5	71.1	10.6	5.1	8.8	4.4	28.9
1.5	[-8]	60.9	6.4	2.5	69.8	12.7	2.9	11.9	2.7	30.2
1.5	[-20]	73.5	5.6	1.0	80.1	11.2	1.9	4.3	2.5	19.9
1.6	[-4]	59.4	10.9	1.5	71.8	10.9	5.1	9.3	2.9	28.2
1.6	[-8]	60.3	5.9	2.6	68.8	11.8	5.4	11.0	3.0	31.2
1.6	[-20]	65.9	5.1	2.5	73.5	10.1	4.3	8.7	3.4	26.5
	R/C	59.9	12.6	2.8	75.3	12.6	1.3	4.6	6.2	24.7

Specific Gravity	Top Fraction	Petrographic Indices			
		Mean Reflectance %	Balance Index %	Strength Index %	Stability Index %
1.4	[-4]	0.87	1.12	3.15	37.1
1.4	[-8]	0.86	1.14	2.99	33.5
1.4	[-20]	0.87	0.54	3.07	31.6
1.5	[-4]	0.86	1.14	3.01	33.8
1.5	[-8]	0.87	1.20	2.98	32.7
1.5	[-20]	0.87	0.70	3.05	33.8
1.6	[-4]	0.86	1.11	2.99	33.6
1.6	[-8]	0.86	1.29	2.87	28.9
1.6	[-20]	0.86	1.07	2.98	33.7
	R/C	0.91	0.82	3.38	42.8

TABLE C3-3C

Petrography

Specific Gravity	Top Fraction	Vitrinoid Distribution 0.6	0.7	0.8	0.9	1.0	1.1
1.4	[-4]	-	8	55	36	-	1
1.4	[-8]	-	20	60	20	-	-
1.4	[-20]	-	14	53	33	-	-
1.5	[-4]	-	19	59	21	1	-
1.5	[-8]	-	13	66	20	1	-
1.5	[-20]	1	18	59	22	-	-
1.6	[-4]	-	16	67	17	-	-
1.6	[-8]	-	19	67	14	-	-
1.6	[-20]	-	30	56	10	4	-
	R/C	-	2	37	58	2	1

Specific Gravity	Top Fraction	Maceral Distribution Vit.	Exin.	Res.	S.Fus.	Fus.	Mic
1.4	[-4]	636	23	-	193	111	37
1.4	[-8]	648	19	-	188	90	55
1.4	[-20]	778	27	-	134	23	38
1.5	[-4]	596	37	-	222	92	53
1.5	[-8]	626	26	-	196	122	30
1.5	[-20]	753	10	-	173	44	20
1.6	[-4]	611	15	-	225	96	53
1.6	[-8]	622	27	-	182	113	56
1.6	[-20]	682	26	-	157	90	45
	R/C	639	30	-	268	49	14

TABLE C3-3D

Microlithotype Analysis % Vol. - C3

		1.4sg	1.5sg	1.6sg
[-4] top size fraction	Liptate	1	-	-
	Clarite	-	3	4
	Vitrite	35	33	33
	Vitrinertite	38	33	32
	Inertinite	16	12	17
	SF 10		9	4
	F 4		2	3
	M -		-	-
	Trimacerite	10	14	14
	Durite	-	-	-
[-8] top size fraction	Liptate	-	-	-
	Clarite	6	6	4
	Vitrite	36	21	24
	Vitrinertite	30	46	35
	Inertinite	15	21	26
	SF 12		7	8
	F 4		5	5
	M -		1	-
	Trimacerite	13	13	11
	Durite	-	-	-
[-20] top size fraction	Liptate	1	-	-
	Clarite	8	3	5
	Vitrite	56	48	32
	Vitrinertite	32	38	26
	Inertinite	6	3	14
	SF 5		2	10
	F -		1	1
	M -		-	1
	Trimacerite	5	7	18
	Durite	-	-	-

TABLE C3-4

Dilatometry

Description	Heating Rate	Pressure	Top Size Mesh	Initial Softening Temp °C	Max. Contraction Temp °C	Max. Dilatation Temp °C	Max. Contraction c%	Max. Dilatation d%	c+d	G-factor	FSI
Clean Coal	3°C/min	4300 psi	[-8+]	391	430.5	491.5	13.1	6.5	19.6	0.96	-
Raw Coal	4.5°C/min	4300 psi	[-20+]	398.5	442	466	13.1	0.0	13.1	0.93	-
	3°C/min	4300 psi	[-8+]	390.5	436	482.5	12.1	1.5	13.6	0.92	-
	3°C/min	3000 psi	[-8+]	399.5	428	458.5	10.2	8.5	18.7	0.99	-
	4.5°C/min	4300 psi	[-8+]	402	438	466	9.8	34.4	44.2	1.04	-
	3°C/min	4300 psi	[-60+]	386.5	437.5	520.5	22.6	-6.4	16.2	0.79	-
	6°C/min	4300 psi	[-60+]	410	422	473.5	22.4	0.0	22.4	0.93	-
Float Sink											
1.4 sg											
[-4] top fraction	3°C/min	3000 psi	[-8+]	411	435	455.5	5.0	15.0	20.0	1.03)	
	4.5°C/min	4300 psi	[-8+]	402	434	459.5	8.2	24.6	32.8	1.03)	7
	3°C/min	4300 psi	[-60+]	399.5	445	450	20.6	-19.0	1.6	0.40)	
[-8] top fraction	3°C/min	3000 psi	[-8+]	421	428	496	1.6	30.6	32.2	1.08)	
	4.5°C/min	4300 psi	[-8+]	408	434.5	522	6.7	41.7	48.4	1.10)	7½
	3°C/min	4300 psi	[-60+]	401.5	435	470.5	25.4	0.0	25.4	0.93)	
[-20] top fraction	3°C/min	4300 psi	[-60+]	401.5	441	457	22.0	-16.9	5.1	0.67	8
1.5 sg											
[-4] top fraction	3°C/min	3000 psi	[-8+]	399	432.5	509.5	9.4	-7.8	1.6	0.43)	
	4.5°C/min	4300 psi	[-8+]	408	441	470.5	6.6	1.6	8.2	0.96)	4½
	3°C/min	4300 psi	[-60+]	393	455	467	22.0	-20.0	2.0	0.36)	
[-8] top fraction	3°C/min	3000 psi	[-8+]	400	434.5	531	6.6	-1.6	5.0	0.81)	
	4.5°C/min	4300 psi	[-8+]	404.5	436	459.5	6.7	-1.7	5.0	0.90)	7
	3°C/min	4300 psi	[-60+]	403	472	507	25.8	-24.6	1.2	0.17)	
[-20] top fraction	3°C/min	4300 psi	[-60+]	407.5	471	-	24.0	-24.0	0.0	*)	6½
1.6 sg											
[-4] top fraction	3°C/min	3000 psi	[-8+]	402	438	459	10.0	-3.0	7.0	0.89)	
	4.5°C/min	4300 psi	[-8+]	418	432	465	1.7	28.8	30.5	1.05)	7½
	3°C/min	4300 psi	[-60+]	405	494	-	28.0	-28.0	0.0	*)	

TABLE C3-4 (continued)

[-8] top fraction	3°C/min	3000 psi	[-8+]	395	433	491	9.8	3.3	13.1	0.95)	
	4.5°C/min	4300 psi	[-8+]	399	438	476	9.7	14.5	24.2	1.02)	8
	3°C/min	4300 psi	[-60+]	408	501	-	23.9	-23.9	0.0	*)	
[-20] top fraction	3°C/min	4300 psi	[-60+]	407	473	-	27.6	-27.6	0.0	*	6_1

* no dilatation

TABLE A1-1A

Sieve Analysis - Raw Coal As Received

Particle Top Size	wt %
over [-4]	58.1
[-4]	13.4
[-8]	14.0
[-20]	3.1
[-30]	5.2
[-60]	2.1
[-100]	4.1

Total = 100.0%

TABLE A1-1C

Sieve Analysis - Specific Gravity Fractions

1.4 sg fraction [-4] Sample wt = 156 g

Particle Size	Wt	Wt %
[-4]	142.7	91.77
[-8]	12.6	8.10
[-20]	-	-
[-60]	-	-
[-100]	0.2	0.13

Total = 100.00

****

1.4 sg fraction [-8] Sample wt = 106.4 g

Particle Size	Wt	Wt %
[-8]	103.5	99.81
[-20]	-	-
[-60]	-	-
[-100]	0.2	0.19

Total = 100.00

****

1.4 sg fraction [-20] Sample wt = 61.2 g

Particle Size	Wt	Wt %
[-20]	15.6	25.74
[-30]	29.8	49.17
[-60]	8.0	13.20
[-100]	7.2	11.88

Total = 99.99

****

TABLE A1-1C (continued)

1.5 sg fraction [-4] Sample wt = 234.5 g

Particle Size	Wt	Wt %
[-4]	230.0	98.33
[-8]	3.3	1.41
[-20]	-	-
[-30]	0.2	0.09
[-60]	0.2	0.09
[-100]	0.2	0.09

Total = 100.01

****

1.5 sg fraction [-8] Sample wt = 180.6 g

Particle Size	Wt	Wt %
[-8]	178.8	98.03
[-20]	1.7	0.93
[-30]	0.6	0.33
[-60]	0.3	0.16
[-100]	1.0	0.55

Total = 100.00

****

1.5 sg fraction [-20] Sample wt = 135.8 g

Particle Size	Wt	Wt %
[-20]	36.1	29.04
[-30]	55.1	44.33
[-60]	8.5	6.84
[-100]	24.6	19.79

Total = 100.00

****

TABLE A1-1C (continued)

1.6 sg fraction [-4] Sample wt = 256.9 g

Particle Size	Wt	Wt %
[-4]	252.0	98.09
[-8]	3.0	1.17
[-20]	0.3	0.12
[-30]	0.6	0.23
[-60]	0.4	0.16
[-100]	0.6	0.23

Total = 100.00

****

1.6 sg fraction [-8] Sample wt = 171.5 g

Particle Size	Wt	Wt %
[-8]	149.1	97.71
[-20]	1.7	1.11
[-30]	0.7	0.46
[-60]	0.2	0.13
[-100]	0.9	0.59

Total = 100.00

****

1.6 sg fraction [-20] Sample wt = 154.0 g

Particle Size	Wt	Wt %
[-20]	33.0	21.74
[-30]	53.1	34.98
[-60]	19.3	12.71
[-100]	46.4	30.57

Total = 100.00

****

TABLE A1-2

Chemical Analyses - Appalachian USA Coal - A1 Hi.Vol

Description	Proximate Analysis db% Moist.	Ash	Vol.M	Fixed C	F.S.I.	Ultimate Analysis db% S	C	H	N	O	Mole Ratio C : H : N : O	Mcf
1.4 sg												
[-4] top fraction	0.82	3.73	27.83	68.44	8½	0.77	80.08	5.00	1.60	8.82	1.00 0.75 0.02 0.08	1.008
[-8] top fraction	0.89	3.53	33.28	63.19	9	0.80	81.33	5.12	2.01	7.21	1.00 0.76 0.02 0.07	1.009
[-20] top fraction	1.24	4.42	28.78	66.80	9	0.83	81.34	5.10	1.19	7.12	1.00 0.75 0.01 0.07	1.012
1.5 sg												
[-4] top fraction	0.98	5.55	33.14	61.31	9	0.77	80.58	5.00	1.61	6.49	1.00 0.74 0.02 0.06	1.010
[-8] top fraction	0.91	5.61	32.84	61.55	9	0.94	82.92	5.23	1.63	3.67	1.00 0.76 0.02 0.03	1.009
[-20] top fraction	1.21	8.00	37.78	54.22	9	0.94	83.19	5.21	1.31	1.35	1.00 0.75 0.01 0.01	1.012
1.6 sg												
[-4] top fraction	0.60	6.30	32.09	61.61	8½	0.96	83.17	5.25	1.08	3.24	1.00 0.76 0.01 0.03	1.006
[-8] top fraction	0.91	5.90	32.74	61.36	9	0.87	76.94	4.61	1.41	10.27	1.00 0.72 0.02 0.10	1.0091
[-20] top fraction	1.32	10.50	35.34	54.16	9	0.80	81.23	5.12	0.97	1.38	1.00 0.76 0.01 0.01	1.013
R/C	1.1	14.25	29.60	55.05	8							1.011

TABLE A1-3A

Petrography - Appalachian Coal - A1

Float Sink

	1.4 sg	1.5 sg	1.6 sg
[-4] top fraction	340V 679V 339V 44E 35E Total R 758	325V 651V 326V 46E 39E Total R 736	322V 639V 317V 36E 40E Total R 722V
[-8] top fraction	356V 742V 386V 24E 23E Total R 789	349V 704V 355V 33E 34E Total R 771	353V 696V 343V 21E 24E Total R 741
[-20] top fraction	392V 768V 376V 21E 35E Total R 814	365V 728V 363V 28E 32E Total R 788	361V 717V 356V 28E 33E Total R 778
Total Vitrinoid	2187	2083	2052
Total Reactives	2361	2295	2241

V - Vintrinoid
E - Exinoid
R - Reactives

TABLE A1-3b

PETROGRAPHY

Specific Gravity	Top Fraction	Reactive Components %				Inert Components %				
		Vitrinite	Semi-Fusinite	Exinite	Total	Semi-Fusinite	Micrinite	Fusinite	Mineral Matter	Total
1.4	[-4]	66.4	2.6	7.7	76.7	5.2	12.7	3.2	2.2	23.3
1.4	[-8]	72.7	1.6	4.6	78.9	3.2	12.9	2.9	2.1	21.1
1.4	[-20]	74.8	1.9	5.5	82.2	3.8	9.8	1.6	2.6	17.8
1.5	[-4]	63.0	1.9	8.2	73.1	3.7	16.1	3.9	3.2	26.9
1.5	[-8]	68.1	1.5	6.5	76.1	3.1	12.2	5.3	3.3	23.9
1.5	[-20]	69.5	1.4	5.7	76.6	2.8	10.2	5.8	4.6	23.4
1.6	[-4]	61.7	2.8	7.3	71.8	5.5	14.6	4.5	3.6	28.2
1.6	[-8]	67.2	2.6	4.3	74.1	5.2	12.3	5.0	3.4	25.9
1.6	[-20]	67.4	1.6	5.7	74.7	3.3	10.5	5.5	6.0	25.3

Specific Gravity	Top Fraction	Petrographic Indices			
		Mean Reflectance %	Balance Index %	Strength Index %	Stability Index %
1.4	[-4]	0.90	0.82	3.30	40.7
1.4	[-8]	0.91	0.71	3.36	41.0
1.4	[-20]	0.93	0.57	3.40	39.7
1.5	[-4]	0.92	0.98	3.41	44.0
1.5	[-8]	0.90	0.84	3.32	41.4
1.5	[-20]	0.90	0.82	3.35	41.9
1.6	[-4]	0.90	1.05	3.31	41.3
1.6	[-8]	0.91	0.93	3.34	42.3
1.6	[-20]	0.90	0.90	3.36	42.5

TABLE A1-3C

PETROGRAPHY

Specific Gravity	Top Fraction	Vitrinoid Distribution 0.7	0.8	0.9	1.0	1.1	1.2
1.4	[-4]	4	45	47	4	-	-
1.4	[-8]	-	37	57	6	-	-
1.4	[-20]	-	24	60	15	1	-
1.5	[-4]	1	35	59	5	-	-
1.5	[-8]	3	42	55	-	-	-
1.5	[-20]	5	37	54	4	-	-
1.6	[-4]	3	43	52	2	-	-
1.6	[-8]	-	47	48	4	1	-
1.6	[-20]	3	38	56	3	-	-

Specific Gravity	Top Fraction	Maceral Distribution Vit.	Exin.	Res.	S Fus.	Fus.	Mic
1.4	[-4]	679	79	-	79	33	130
1.4	[-8]	742	47	-	49	30	132
1.4	[-20]	768	56	-	59	16	101
1.5	[-4]	651	85	-	58	40	166
1.5	[-8]	704	67	-	48	55	126
1.5	[-20]	728	60	-	44	61	107
1.6	[-4]	639	76	-	86	47	152
1.6	[-8]	696	45	-	80	52	127
1.6	[-20]	717	61	-	52	58	112

TABLE A1-4

Dilatometry

Description	Heating Rate	Pressure	Top Size Mesh	Initial Softening Temp °C	Max. Contraction Temp °C	Max. Dilatation Temp °C	Max. Contraction c%	Max. Dilatation d%	c+d	G-factor	FSI
Float Sink											
1.4 sg											
[-4] top fraction	3°C/min	3000 psi	[-8+]	358	405	474	14.7	188.5	203.2	1.12)	
	4.5°C/min	4300 psi	[-8+]	383	411	489	11.1	223.8	234.9	1.12)	8½
	3°C/min	4300 psi	[-60+]	348	409	460	29.3	181.0	210.3	1.11)	
[-8] top fraction	3°C/min	3000 psi	[-8+]	352	403	476	13.6	198.3	211.9	1.15)	
	4.5°C/min	4300 psi	[-8+]	356	409	480	15.0	231.7	246.7	1.15)	9
	3°C/min	4300 psi	[-60+]	371	410	465	28.1	171.9	200.0	1.09)	
(-20] top fraction	3°C/min	4300 psi	[-60+]	360	408	517	27.4	146.7	174.1	1.14	9
1.4 sg											
[-4] top fraction	3°C/min	3000 psi	[-8+]	364	408	530	14.5	175.8	190.3	1.19)	
	4.5°C/min	4300 psi	[-8+]	376	412	474	13.3	193.3	206.6	1.11)	9
	3°C/min	4300 psi	[-60+]	367	410	477	30.0	163.3	193.3	1.10)	
[-8] top fraction	3°C/min	3000 psi	[-8+]	361	403	463	14.7	178.7	193.4	1.12)	
	4.5°C/min	4300 psi	[-8+]	374	410	476	13.5	230.5	244.0	1.12)	9
	3°C/min	4300 psi	[-60+]	348	411	458	28.3	155.0	183.3	1.10)	
[-20] top fraction	3°C/min	4300 psi	[-60+]	372	417	519	27.4	100.0	127.4	1.10	9
1.6 sg											
[-4] top fraction	3°C/min	3000 psi	[-8+]	361	406	463	14.5	169.3	183.8	1.12)	
	4.5°C/min	4300 psi	[-8+]	372	412	475	13.9	208.7	222.6	1.12)	8½
	3°C/min	4300 psi	[-60+]	372	412	507	28.3	158.3	186.6	1.12)	
[-8] top fraction	3°C/min	3000 psi	[-8+]	365	403	498	10.3	187.9	198.2	1.16)	
	4.5°C/min	4300 psi	[-8+]	357	406	474	13.7	208.6	222.3	1.14)	9
	3°C/min	4300 psi	[-60+]	370	413	460	28.3	145.0	173.3	1.08)	
[-20] top fraction	3°C/min	4300 psi	[-60+]	391	425	454	24.6	35.4	60.0	1.01	9

TABLE A1-3D

Microlithotype Analysis % Vol. - A1

		1.4sg	1.5sg	1.6sg
[-4] top size fraction	Liptate	-	1	-
	Clarite	17	10	12
	Vitrite	25	25	24
	Vitrinertite	25	37	32
	Inertinite	2	4	2
	SF			1
	F	2	2	1
	M		2	
	Trimacerite	31	30	23
	Durite	-	3	7
[-8] top size fraction	Liptate	-	-	-
	Clarite	5	16	13
	Vitrite	46	32	40
	Vitrinertite	30	25	20
	Inertinite	3	4	2
	SF			
	F	1	4	
	M	1		
	Trimacerite	15	22	22
	Durite	1	7	3
[-20] top size fraction	Liptate	-	-	-
	Clarite	9	9	11
	Vitrite	36	38	46
	Vitrinertite	35	28	21
	Inertinite	5	3	4
	SF	3		1
	F	2	2	3
	M		1	
	Trimacerite	9	18	16
	Durite	6	4	2

TABLE A2-1A

Sieve Analysis - Raw Coal As Received

Particle Top Size	wt %
[+4]	2.6
[-4]	17.6
[-8]	34.4
[-20]	9.1
[-30]	17.0
[-60]	6.6
[-100]	12.7

Total = 100.0%

TABLE A2-1C

Sieve Analysis - Specific Gravity Fractions

1.4 sg fraction [-4] Sample wt = 115.4 g

Particle Size	Wt	Wt %
[-4]	105.2	92.85
[-8]	7.7	6.80
[-20]	-	-
[-30]	-	-
[-60]	-	-
[-100]	0.4	0.35

Total = 100.00

****

1.4 sg fraction [-8] Sample wt = 245.0 g

Particle Size	Wt	Wt %
[+8]	0.5	0.21
[-8]	229.0	93.89
[-20]	13.1	5.37
[-30]	0.5	0.21
[-60]	0.1	0.04
[-100]	0.7	0.28

Total = 100.00

****

1.4 sg fraction [-20] Sample wt = 335.2 g

Particle Size	Wt	Wt %
[-20]	62.7	18.94
[-30]	150.8	45.55
[-60]	55.6	16.79
[-100+]	62.0	18.72

Total = 100.00

****

TABLE A2-1C (continued)

1.5 sg fraction [-4] Sample wt = 81.4 g

Particle Size	Wt	Wt %
[-4]	73.0	90.12
[-8]	7.4	9.14
[-20]	0.1	0.12
[-30]	0.1	0.12
[-60]	0.1	0.12
[-100]	0.3	0.37

Total = 99.99

****

1.5 sg fraction [-8] Sample wt = 217.0 g

Particle Size	Wt	Wt %
[+8]	4.2	1.94
[-8]	207.2	95.93
[-20]	4.2	1.94
[-30]	0.1	0.05
[-60]	0.1	0.05
[-100]	0.2	0.09

Total = 100.00

****

1.5 sg fraction [-20] Sample wt = 301.4 g

Particle Size	Wt	Wt %
[-20]	60.2	20.29
[-30]	119.8	40.38
[-60]	47.0	15.84
[-100]	69.7	23.49

Total = 100.00

****

TABLE A2-1C (continued)

1.6 sg fraction [-4] Sample wt = 96.8 g

Particle Size	Wt	Wt %
[-4]	88.4	91.99
[-8]	6.4	6.66
[-20]	0.7	0.73
[-30]	0.3	0.31
[-60]	-	-
[-100]	0.3	0.31

Total = 100.00

****

1.6 sg fraction [-8] Sample wt = 183.9 g

Particle Size	Wt	Wt %
[-8]	179.6	98.25
[-20]	2.7	1.48
[-30]	-	-
[-60]	-	-
[-100]	0.5	0.27

Total = 100.00

****

1.6 sg fraction [-20] Sample wt = 131.3 g

Particle Size	Wt	Wt %
[+20]	0.6	0.46
[-20]	27.8	21.38
[-30]	56.4	43.38
[-60]	18.0	13.85
[-100]	27.2	20.92

Total = 99.99

****

TABLE A2-2

Chemical Analyses - Appalachian USA Coal - A2 Hi.Vol.

Description	Proximate Analysis db% Moist.	Ash	Vol.M	Fixed C	F.S.I.	Ultimate Analysis db% S	C	H	N	O	Mole Ratio C : H : N : O	Mcf
1.4 sg												
[-4] top fraction	0.10	5.45	26.29	68.26	8½	0.80	82.97	4.60	0.61	5.57	1.00 0.67 0.006 0.05	1.001
[-8] top fraction	0.10	4.85	26.51	68.64	8½	0.81	83.03	4.42	1.60	5.29	1.00 0.64 0.017 0.05	1.001
[-20] top fraction	0.10	4.20	27.50	68.30	9	0.84	84.87	4.83	1.93	3.33	1.00 0.68 0.020 0.03	1.001
1.5 sg												
[-4] top fraction	0.28	7.16	25.36	67.48	8	0.82	81.26	4.37	1.39	5.00	1.00 0.65 0.015 0.05	1.0028
[-8] top fraction	0.31	6.06	25.90	68.04	8½	1.10	82.59	4.71	1.66	3.88	1.00 0.68 0.017 0.04	1.0031
[-20] top fraction	0.17	5.87	25.97	68.16	9	0.91	82.97	4.68	1.88	3.69	1.00 0.68 0.019 0.03	1.0017
1.6 sg												
[-4] top fraction	0.03	9.33	24.61	66.06	8	0.81	80.25	4.44	0.78	4.39	1.00 0.66 0.008 0.04	1.0003
[-8] top fraction	0.03	8.13	25.40	66.47	8	0.80	80.79	4.58	1.59	4.11	1.00 0.68 0.017 0.04	1.003
[-20] top fraction	0.03	6.65	25.58	67.77	9	0.73	82.52	4.64	1.88	3.58	1.00 0.68 0.020 0.03	1.003

TABLE A2-3A

Petrography - Appalachian USA Coal - A2

	1.4 sg	1.5 sg	1.6 sg
[-4] top fraction	V-668	V-612	V-590
	E- 8	E- 15	E- 42
	SF-114	SF-120	SF-131
	F- 36	F- 62	F- 79
	M-174	M-191	M-158
[-8] top fraction	V-690	V-644	V-600
	E- 2	E- 10	E- 40
	SF-124	SF-132	SF-178
	F- 20	F- 52	F- 50
	M-164	M-162	M-132
[-20] top fraction	V-744	V-710	V-624
	E- 14	E- 20	E- 30
	SF-112	SF- 90	SF-122
	F- 52	F- 52	F-110
	M- 78	M-128	M-114

TABLE A2-3B

PETROGRAPHY

Specific Gravity	Top Fraction	Reactive Components %				Inert Components %				
		Vitrinite	Semi-Fusinite	Exinite	Total	Semi-Fusinite	Micrinite	Fusinite	Mineral Matter	Total
1.4	[-4]	64.6	3.7	0.8	69.1	7.4	16.9	3.5	3.1	30.9
1.4	[-8]	67.2	4.0	0.2	71.4	8.0	15.9	1.9	2.8	28.6
1.4	[-20]	72.5	3.6	1.4	77.5	7.3	7.6	5.1	2.5	22.5
1.5	[-4]	58.8	3.8	1.4	64.0	7.7	18.3	5.9	4.1	36.0
1.5	[-8]	62.1	4.2	1.0	67.3	8.5	15.6	5.0	3.6	32.7
1.5	[-20]	68.6	2.9	1.9	73.4	5.8	12.4	5.0	3.4	26.6
1.6	[-4]	55.8	4.1	4.0	63.9	8.3	15.0	7.5	5.3	36.1
1.6	[-8]	57.2	5.7	3.8	66.7	11.3	12.6	4.8	4.6	33.3
1.6	[-20]	60.0	3.9	2.9	66.8	7.8	11.0	10.6	3.8	33.2

Specific Gravity	Top Fraction	Petrographic Indices			
		Mean Reflectance %	Balance Index %	Strength Index %	Stability Index %
1.4	[-4]	1.06	1.13	3.99	53.9
1.4	[-8]	1.07	1.04	4.09	56.0
1.4	[-20]	1.08	0.75	4.10	56.0
1.5	[-4]	1.04	1.43	3.84	47.8
1.5	[-8]	1.09	1.22	4.00	53.0
1.5	[-20]	1.07	0.93	4.10	56.7
1.6	[-4]	1.06	1.45	3.95	49.7
1.6	[-8]	1.05	1.28	3.93	51.5
1.6	[-20]	1.05	1.27	3.91	51.5

TABLE A2-3C

PETROGRAPHY

Specific Gravity	Top Fraction	Vitrinoid Distribution 0.8	0.9	1.0	1.1	1.2	1.3
1.4	[-4]	4	12	48	36	-	-
1.4	[-8]	-	20	40	32	8	-
1.4	[-20]	-	20	36	40	4	-
1.5	[-4]	-	32	44	20	4	-
1.5	[-8]	-	8	60	28	4	-
1.5	[-20]	-	20	40	36	4	-
1.6	[-4]	-	20	40	36	4	-
1.6	[-8]	-	32	40	20	8	-
1.6	[-20]	-	32	44	16	8	-

Specific Gravity	Top Fraction	Maceral Distribution Vit.	Exin.	Res.	S.Fus.	Fus.	Mic
1.4	[-4]	668	8	-	114	36	174
1.4	[-8]	690	2	-	124	20	164
1.4	[-20]	744	14	-	112	52	78
1.5	[-4]	612	15	-	120	62	191
1.5	[-8]	644	10	-	132	52	162
1.5	[-20]	710	20	-	90	52	128
1.6	[-4]	590	42	-	131	79	158
1.6	[-8]	600	40	-	178	50	132
1.6	[-20]	624	30	-	122	110	114

TABLE A2-3D

Microlithotype Analysis % Vol. - A2

		1.4sg	1.5sg	1.6sg
[-4] top size fraction	Liptate	-	-	-
	Clarite	-	3	1
	Vitrite	21	14	14
	Vitrinertite	50	48	51
	Inertinite	11	9	9
	SF	2	1	3
	F	3	4	3
	M	2	2	1
	Trimacerite	16	22	20
	Durite	2	4	5
[-8] top size fraction	Liptate	-	-	-
	Clarite	2	2	4
	Vitrite	22	17	14
	Vitrinertite	48	57	49
	Inertinite	14	9	10
	SF	6		4
	F	1		2
	M	3		1
	Trimacerite	10	15	19
	Durite	4	-	4
[-20] top size fraction	Liptate	-	-	-
	Clarite	-	1	3
	Vitrite	30	31	30
	Vitrinertite	49	45	38
	Inertinite	5	8	6
	SF	1	1	1
	F	2	1	2
	M	2	3	1
	Trimacerite	9	15	15
	Durite	7	-	8

TABLE A2-4

Dilatometry

Description	Heating Rate	Pressure	Top Size Mesh	Initial Softening Temp °C	Max. Contraction Temp °C	Max. Dilatation Temp °C	Max. Contraction c%	Max. Dilatation d%	c+d	G-factor	FSI
Float Sink											
1.4 sg											
[-4] top fraction	3°C/min	3000 psi	[-8+]	381	405	490	11.9	247.4	259.3	1.13)	
	4.5°C/min	4300 psi	[-8+]	378	409	490	12.4	260.2	272.6	1.13)	8½
	3°C/min	4300 psi	[-60+]	373	410	479	25.6	213.5	239.1	1.11)	
[-8] top fraction	3°C/min	3000 psi	[-8+]	378	402	479	10.8	253.0	263.8	1.12)	
	4.5°C/min	4300 psi	[-8+]	387	411	480	14.5	293.5	308.0	1.11)	8½
	3°C/min	4300 psi	[-60+]	375	407	483	26.7	254.1	280.8	1.11)	
(-20] top fraction	3°C/min	4300 psi	[-60+]	380	407	484	25.5	287.6	313.1	1.11)	9
1.4 sg											
[-4] top fraction	3°C/min	3000 psi	[-8+]	378	410	504	13.1	208.4	221.5	1.14)	
	4.5°C/min	4300 psi	[-8+]	380	410	482	12.1	226.7	238.8	1.12)	8
	3°C/min	4300 psi	[-60+]	385	417	499	24.7	181.8	206.5	1.11)	
[-8] top fraction	3°C/min	3000 psi	[-8+]	376	405	513	11.8	249.7	261.5	1.16)	
	4.5°C/min	4300 psi	[-8+]	385	413	491	11.3	283.0	294.3	1.13)	8½
	3°C/min	4300 psi	[-60+]	376	409	481	26.0	225.9	251.9	1.11)	
[-20] top fraction	3°C/min	4300 psi	[-60+]	371	408	509	20.9	235.9	256.8	1.15	9
1.6 sg											
[-4] top fraction	3°C/min	3000 psi	[-8+]	375	406	476	11.3	183.0	194.3	1.12)	
	4.5°C/min	4300 psi	[-8+]	381	412	485	9.9	226.9	236.8	1.12)	8
	3°C/min	4300 psi	[-60+]	380	417	490	21.5	153.8	175.3	1.11)	
[-8] top fraction	3°C/min	3000 psi	[-8+]	381	408	472	12.6	215.9	228.5	1.10)	
	4.5°C/min	4300 psi	[-8+]	378	409	484	10.6	243.1	253.7	1.13)	8
	3°C/min	4300 psi	[-60+]	383	413	488	23.7	207.6	231.3	1.11)	
[-20] top fraction	3°C/min	4300 psi	[-60+]	378	409	477	26.2	231.8	258.0	1.10	9

APPENDIX B

COMPARISON OF SPECIFICATIONS FOR THE RUHR DILATOMETER AND PROCEDURES USED

Table Comparison of Parameters Affecting Dilatation

Dilatometer Standard or Specification	Heating Rate (°C/min)	Particle Top Size and Consist (mm)	Storage of Ground Coal Sample Before Determination (if not used immediately)	Sample Size, Wetting	Sample Compaction Method, Maximum Force and Pressure (calculated from press piston area)
ISO 349 (48)	3±3% within any 5-min period 340 to 550°C	0.16 100% through 0.2 70-85% through 0.1 55-70% through 0.06	oxygen-free nitrogen or freshly boiled water	10g 1 ml water	falling weight ram and tamping pin
DIN 51739 (89)	3	0.20	oxygen-free environment	10g air-dried 1 ml water	hammer and tamping ram and spindle press without force gauge
Ruhr Procedure, Jorgensen (54)	3 to 550°C	0.20 100% through 0.2 70-85% through 0.1 55-70% through 0.063	----------	10g air-dried 1 ml water containing 0.5 g/l wetting agent	hammer and tamping ram and spindle press up to 70 kg_f/mm^2 = 100,000 psi F = 4,100 lb_f
BSI-BCRA (16)	3±0.05 250 to 600°C	0.212 100% through 0.212 60-70% through 0.125 30-40% through 0.063	sealed glass phials in argon atmosphere	10g air-dried 1 ml water	hammer and tamping ram and spindle press up to 1.5 tonnes = 3,300 lb_f P = 81,000 psi
Italsider Corp. Manual (51)	3 to 500°C	0.20 60-80% between 0.10 and 0.20	refrigerate	10g dried 24h non-oxid.atm. 1 ml of 1% soap soln.	hammer and tamping ram and spindle press up to 2 tonnes = 4,400 lb_f P = 110,000 psi
STELCO Manual (103)	3 320 to 500°C	0.250	----------	6g 7 drops of 0.5g/l wetting agent soln.	hammer and tamping ram and spindle press up to 1634 kg_f = 1.8 tons P = 85,000 psi

Table continued

Dilatometer Standard or Specification	Length and End Diameters of Pencil (mm) and end to be trimmed	Piston Mass (g)	Dilatometer Tube Inner Diameter, Piston Diameter, Clearance (mm)	Preheat Temperature, Dependence on Coal Rank
ISO 349 (48)	60 ± 0.25 6.0 ± 0.02 7.2 ± 0.02 trim wide end	150 ± 5	8 ± 0.05 7.8 0.2 ± 0.05	330°C or if T1<350°C, 20°C below T1
DIN 51739 (89)	60 6.2 7.4 trim narrow end	--------	8 -------- --------	20°C below T1 VM daf / preheat temperature 10 / 450°C 16 / 400°C 22 / 350°C 30 / 320°C
Ruhr Procedure, Jorgensen (54)	60 ± 0.5 6.0 ± 0.04 7.2 ± 0.04 trim wide end	--------	8 -------- --------	30°C below T1 Type of Coal / preheat temperature gas flame coal, gas coal / 320°C bituminous coal, steam coal / 340°C semi-anthracite coal / 400°C anthracite / 450°C
BSI-BCRA (16)	60 ± 0.5 6.2 ± 0.05 7.4 ± 0.05 trim narrow end	150 ± 5 combined wt. piston-pen assembly	8.00 ± 0.05 7.80 ± 0.05 0.20 ± 0.05	75°C below T1 VM daf / preheat temperature 38 / 265°C 28 / 295°C 18 / 325°C 15 / 355°C
Italsider Corp. Manual (51)	60 ± 0.25 6.0 ± 0.02 7.2 ± 0.02 trim wide end	100	8 ± 0.05 -------- <0.2	as for Jorgensen above
STELCO Manual (103)	60 ± 0.5 6.0 ± 0.06 7.2 ± 0.04 trim wide end	90	8.0 7.8 0.2	320°C

Table continued

Dilatometer Standard or Specification	Tolerances for Parallel, Duplicate Determinations: c	d	T1,T2,T3	d > 300% CASE	Procedure for determining if mould and tubes should be rejected due to wear
ISO 349 (48)	-------	T(1 + d/100)	------	----------	YES, both, tubes after 100 runs and after each 25 subsequent tests
DIN 51739 (89)	± 3.5% of c for each	± 3.5% of d for each	------	----------	NO
Ruhr Procedure, Jorgensen (54)	5%	d allowable difference <50 7 50-100 10 100-200 14 >200 20	12°C	use 30mm mid-portion of pencil, double values of contraction and dilatation	YES, mould only
BSI-BCRA (16)	5%	d allowable difference 0-50 5 51-100 10 101-200 15 >200 20	7°C	reported as d > 300%	YES, tubes only, checked after 100, 150, 200 runs
Italsider Corp. Manual (51)	-------	d allowable difference <50 6 50-150 10 150-220 16 220-300 20	± 5°C	----------	YES, mould only
STELCO Manual (103)	5%	as for Jorgensen above	12°C	as for Jorgensen above	NO

POOR

QUALITY

ORIGINAL